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Radiation Detection Equipment (RDE) Comparative Evaluation Test Program
Volume 1—Point Source Measurements

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13. ABSTRACT *(Maximum 200 words)*
Radiation detection equipment (RDE) will be used under the START Treaty to verify that air-launched cruise missiles (ALCM) declared to be non-nuclear do not contain nuclear warheads and to verify that certain containers do not contain radiation attenuating material. Under the Intermediate-Range Nuclear Forces (INF) Treaty, neutron RDE was used and it is proposed that the same RDE be used for the START Treaty. However, the On-Site Inspection Agency (OSIA) has established a requirement for commercially available, lighter weight and smaller equipment than the INF RDE. As a result of the OSIA requirements, the DNA undertook a test project to evaluate selected neutron RDE to determine if any of the available instruments could satisfy the START monitoring requirements.

Several different RDE, including the INF RDE, were exposed to calibration sources at Andrews Air Force Base and the Los Alamos National Laboratory (LANL) and to actual nuclear warheads at LANL. The results of these tests indicated that, unless there are significant changes in the Treaty procedures related to neutron source strength, detector-to-source distance, and/or data accumulation time, only one commercially available RDE could favorably compare with the INF RDE. However, there would be little savings in weight or size.

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PREFACE

The DNA Project Manager is Lt. Col. Benard H. Simelton from the Arms Control and Test Limitations Directorate. The primary authors of the report are John H. McNeilly and Bernice D. Rothstein from the Center for Verification Research (CVR). Other CVR personnel contributing to the report are: Mr. Ed Hamilton, Mr. Robert Mitchell, Mr. Charles Shaw, and Mr. Darnell Cephas.

The authors wish to acknowledge the following individuals: Dr. Bob Shipman, Dr. Warnick Kernan, and Dr. Paul Guss from EG&G Energy Measurements at Andrews AFB for the use of their facilities and their support throughout those tests; Dr. Keith W. Marlow and Mr. Pete Havey from Sandia National Laboratories for participating in the tests at Andrews AFB; Dr. Steve Dupree from the Office of Under Secretary of Defense for Acquisition (OUSD(A)) for the many helpful discussions; Dr. M. William Johnson from the Los Alamos National Laboratory for his excellent support at the Los Alamos Simulation Facility (LASF) and the many helpful technical discussions; Sgt Philip Duncan from AFTAC/DOOT for supporting the tests at the LASF; and Mr. Michael O'Connell from the Office of Arms Control, Department of Energy for providing the INF detector and sponsoring the use of the LASF.

The following vendors are also acknowledged for their cooperation and loan of their respective instrumentation: Ludlum Measurements, Inc., Sweetwater, Texas; Canberra Nuclear, Jomar Systems Division, Los Alamos, New Mexico; and, TSA Systems, Ltd., Longmont, Colorado.

Finally, Professor Martin E. Nelson and Associate Professor Mark J. Harper from the U.S. Naval Academy are acknowledged for providing the bubble dosimeters and participating in the tests at Andrews AFB.

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RADIATION DETECTION EQUIPMENT (RDE) COMPARATIVE EVALUATION TEST PROGRAM

1.1 INTRODUCTION.

1.2 OBJECTIVE.

The objective of the test program described in this report is to evaluate various portable, commercially available neutron detectors for the purpose of determining their suitability for START Treaty monitoring applications.

1.3 BACKGROUND.

Under the terms of the Strategic Arms Reduction Talks (START) Treaty the use of radiation detection equipment (RD) is permitted to determine that items declared not to be nuclear warheads on air launched cruise missiles (ALCM's) do not emit nuclear radiation. In addition, if inspectors identify a container large enough to contain the smallest of the declared nuclear ALCM types, they have the right to have a selected number of those containers opened for visual inspection of the interior of the container. Further, a radiation source may be introduced into the interior of the container and radiation measurements made exterior to the container. The purpose of the measurement is to determine that the container walls do not consist of materials that provide significant attenuation of the radiation.

The precedent for radiation detection equipment for Treaty monitoring activities was established under the Intermediate-Range Nuclear Forces (INF) Treaty wherein the distinguishability between the allowed SS-25 missile and banned SS-20 missile was accomplished through neutron radiation detection methods. Since the Former Soviet Union accepted neutron radiation detection methods under INF, it is believed that the same method for START application is likely to be accepted.

The On-Site Inspection Agency (OSIA) is the implementer of on-site inspections and provides requirements to technology developers for incorporating selected features that are desirable to satisfy operational requirements. Procedures developed under the Treaty Protocols also introduce requirements that inspection equipment must satisfy. The combination of the technical task, operational requirements and treaty procedures usually places significant demands on the monitoring equipment.

The neutron sources that are included as check-out and standardization sources with the INF radiation detectors are the sources of choice for the ALCM container radiation attenuation measurements. These neutron sources have low strengths, which when coupled with potential attenuation by an intervening material, place very stringent requirements on the neutron detection equipment. Also, since the treaty-allowed procedures usually restrict the separation distance between the neutron source and the detector and the time allotted for acquiring data is relatively short, the neutron detector sensitivity must be high.

The memorandum containing OSIA's requirements for RDE (presented in Appendix A) states that the Russians do not wish to use the INF RDE (however, the Russians have not suggested alternative RDE) and specifies the desired equipment features for alternate RDE. In order to determine if the commercially available equipment can satisfy the monitoring requirements, a test program was established to evaluate candidate instruments.

The test program consisted of three phases: (1) a screening test designed to use a readily accessible neutron source (available at Andrews Air Force Base (AAFB)) and instruments borrowed from vendors or government agencies to perform a comparative evaluation test and eliminate obvious non-performers, (2) a more rigorous comparative evaluation test of those instruments surviving the screening test, performed at the Los Alamos Simulation Facility (LASF) where suitable calibration sources and realistic surrogates for the nuclear ALCM's were available, and (3) a field test at an operational Air Force base, such as Carswell AFB, if the results from the LASF tests warrant.

This volume of the report describes the tests performed and the results obtained from the phase 1 and 2 tests. Chapter 2 contains a description of the phase 1 (AAFB) test procedures, test results, and application of those results in preparation for the phase 2 (LASF) tests. Chapter 3 contains descriptive information relative to the phase 2 tests including an interpretation of the effects of a variety of shielding materials on the RDE response. Appendices provide OSIA's requirements for new RDE, vendor information on the tested RDE, and tables of the raw data from the measurements at Andrews AFB and the calibration sources at LASF. The classified Volume 2 of this report presents the results of measurements of the two "special" sources and the application of the measurement results to the assessment of the RDE performance under the provisions of the START RDE procedures.

The INF detector was the most sensitive of the neutron detectors evaluated in the tests.

SECTION 2

PHASE 1 - SCREENING TEST

2.1 OVERVIEW.

The screening tests were performed in an aircraft hangar at Andrews Air Force Base, MD, using a Californium-252 neutron source in unmoderated and moderated configurations. The neutron detection instruments were energized without the neutron source present to provide background data. A pure gamma-ray source (^{60}Co) was used to assure the detectors were not responding to gamma-rays. Two additional "qualifying" tests were performed: (1) a radial measurement of the neutron environment from the source to two meters to provide assurance that the neutron field was consistent with the "inverse square" law, and (2) at the one meter distance from the source, where the comparative evaluation data was to be acquired, detector locations were established approximately every 85 centimeters around that circumference. Measurements were made with each instrument at each location on the circumference to assure no location bias or scattering from adjacent instruments. If the results of this latter test showed no bias then the one meter results could be pooled for the evaluation comparison.

The following paragraphs provide additional details concerning the radiation sources, the neutron detection instruments, the test geometry, the test procedures, and the methods used in the data analysis.

2.2 RADIATION SOURCES.

2.2.1 Neutron Source.

The ^{252}Cf neutron source emitted 2.0 x 10^6 (plus or minus 15%) neutrons per second. The source also contained 400 microcuries of ^{133}Ba and 20 microcuries of ^{137}Cs. The source was encapsulated in a small stainless steel vial, and, for the purposes of this test was considered to be a point source.

2.2.2 Gamma-Ray Source.

The ^{60}Co gamma-ray source was 3.1 millicuries and was encapsulated in a manner similar to the ^{252}Cf. This was also considered to be a point source for the purposes of this test.

2.3 RADIATION DETECTION EQUIPMENT.

Table 2-1 lists the neutron detectors tested and summarizes some of the more important characteristics. Figures 2-1 through 2-7 depict the individual instruments and Appendix B contains descriptive literature for each instrument.

Table 2-1. RDE instruments.

Make/Model	Detector (Type)	Construction	Weight	Dimension	Electronics (Type)	Weight	Dimension
INF (Sandia National Laboratory)	^3He	Cd covered poly box 12-25 cm L ^3He tubes	14 kg (31 lbs)	6.35 cm W 29.5 cm H 25.4 cm L	Digital	2 kg (4.4 lbs)	13.2 cm W 12.7 cm H 26.7 cm L
LUDLUM 15	BF_3	Cd lined poly. cyl. 7.6 cm Dia x 17.8 cm L	3.5 kg (7.5 lbs)	8.6 cm W 26.6 cm H 19 cm L	Analog	(mounted on detector)	N/A
LUDLUM 12-4	BF_3	Cd lined poly sphere 22.9 cm Dia	9.5 kg (21 lbs)	2.3 cm W 43 cm H 27 cm L	Analog	(mounted on detector)	N/A
LUDLUM 42-9	BF_3	Cd lined poly cyl. 7.6 cm Dia x 17.8 cm L	1.8 kg (4 lbs)	7.6 cm W 15.2 cm H 17.8 cm L	Model 2221 Digital & Analog	2.3 kg (5 lbs)	11.4 cm W 19.1 cm H 24.1 cm L
JOMAR JSP-12	^3He	Cd lined poly cyl. 2-20.3 cm L ^3He tubes	9 kg (20 lbs)	24.1 cm D 39.1 cm H	Model JHH-41 Digital	1.8 kg (4 lbs)	12.6 cm W 9.00 cm H 20.0 cm L
TSA NNV-470As	$^6LiI(Eu)$	2.5 cm-Dia No poly or Cd	1.8 kg (4 lbs)	12 cm W 10.5 cm H 21 cm L	Digital (preset 20s count time)	(self contained)	N/A
BD-100R PND	Elastic Polymer	vial containing superheated drops in suspension	57 grams (0.125 lbs)	2 cm Dia. 15 cm L	N/A Visual Indication or Optical Readers	N/A	N/A

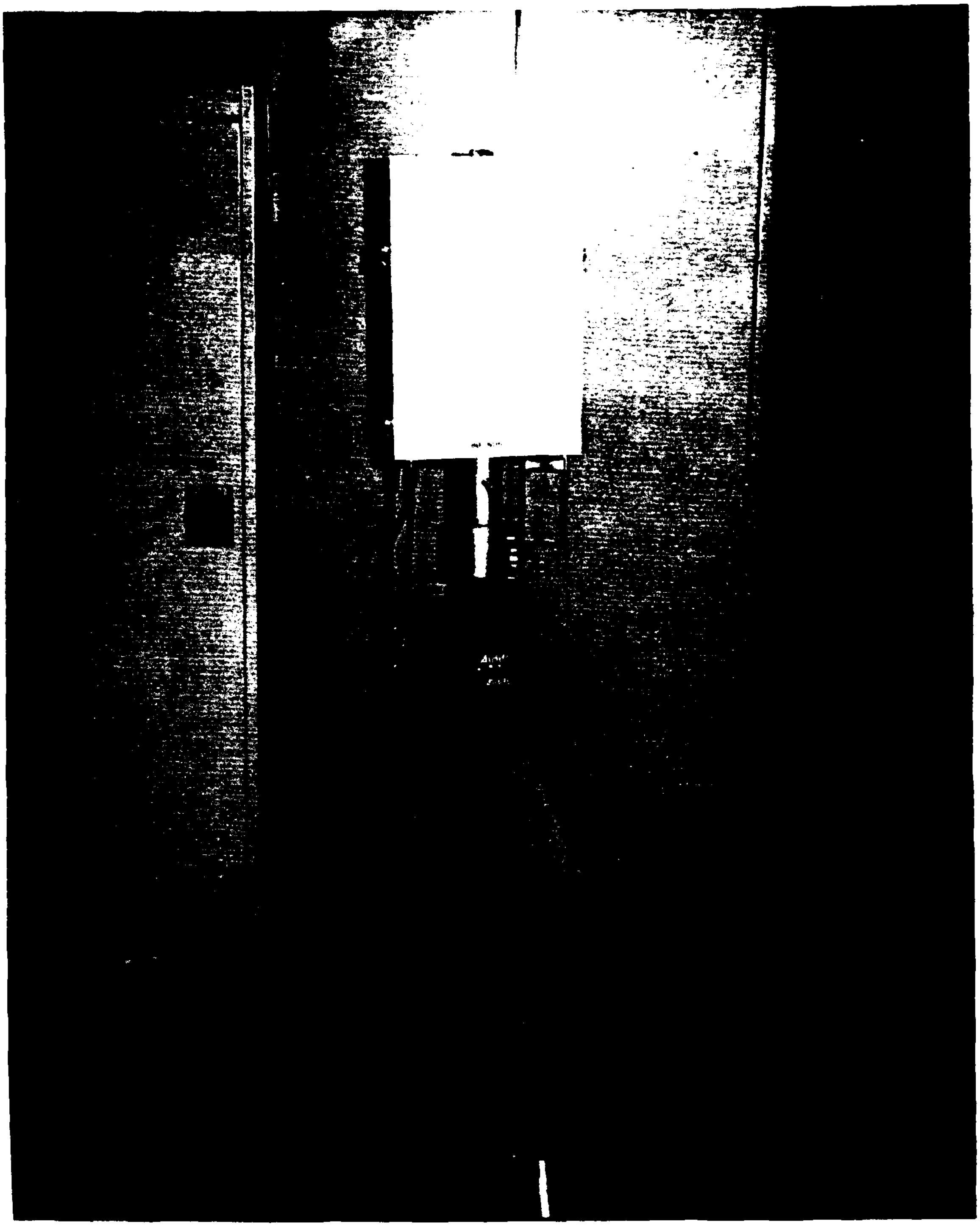

Figure 2–1. INF neutron detector.

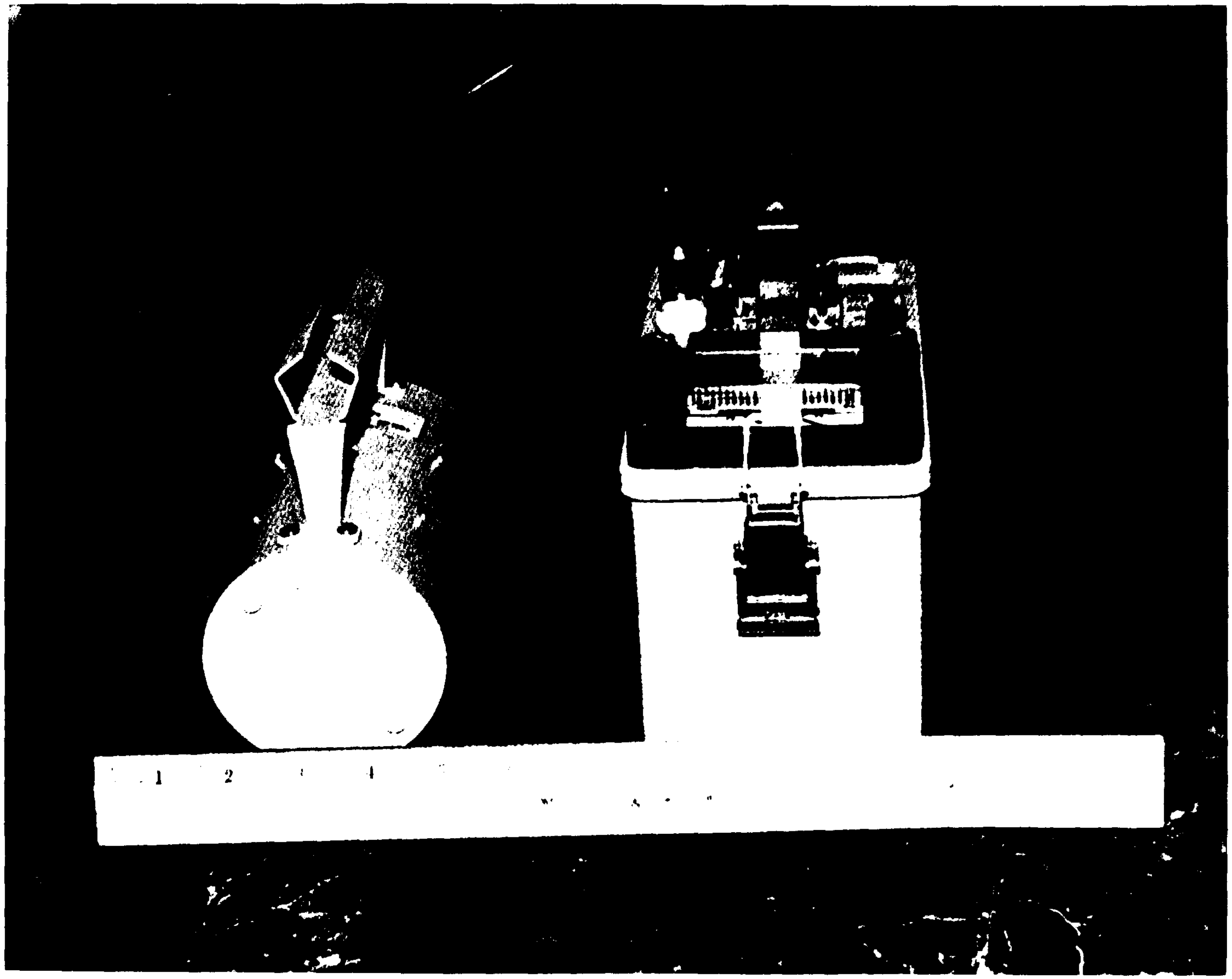

Figure 2–2. Ludlum Model 15 neutron detector

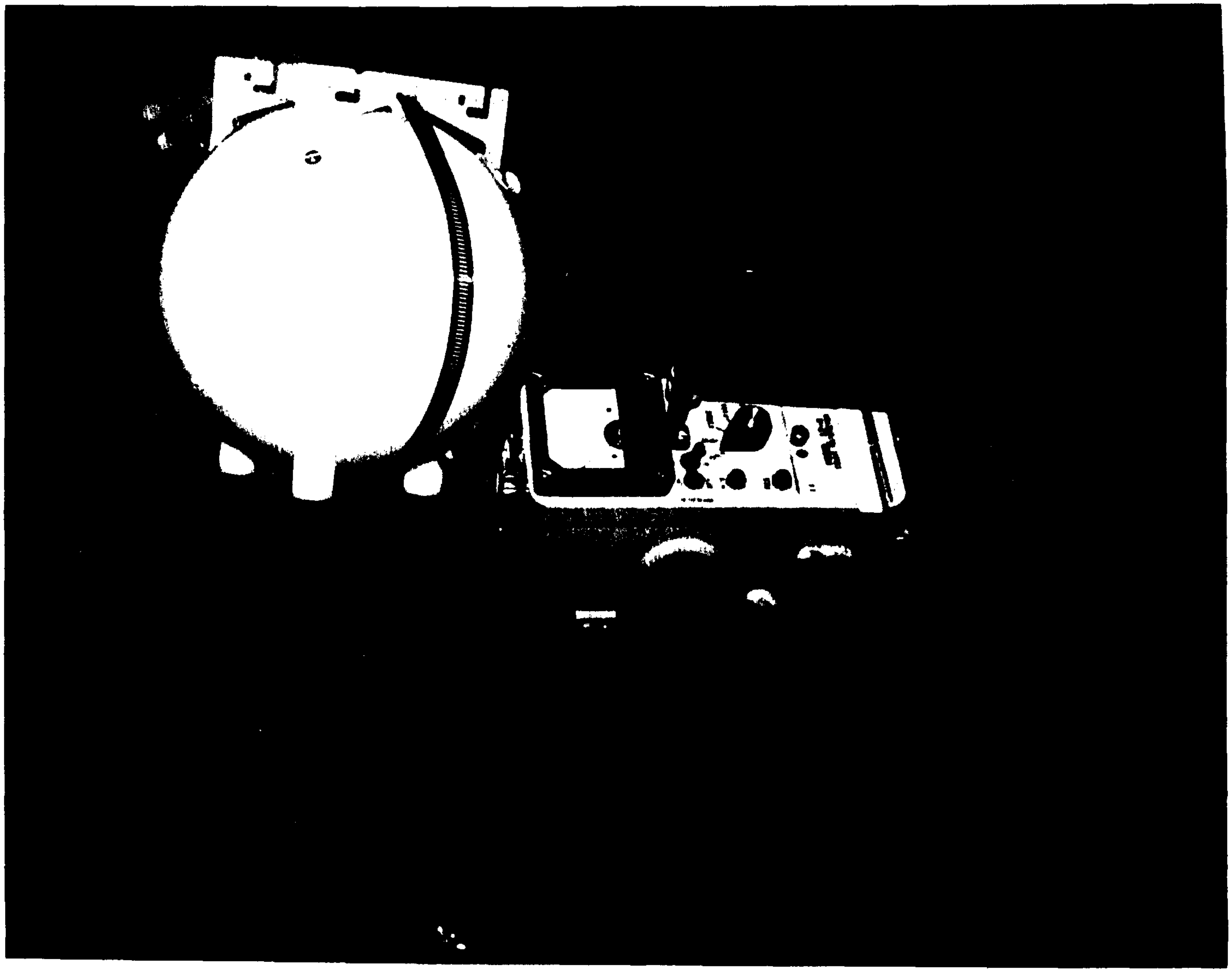

Figure 2–3. Ludlum Model 12–4 neutron detector.

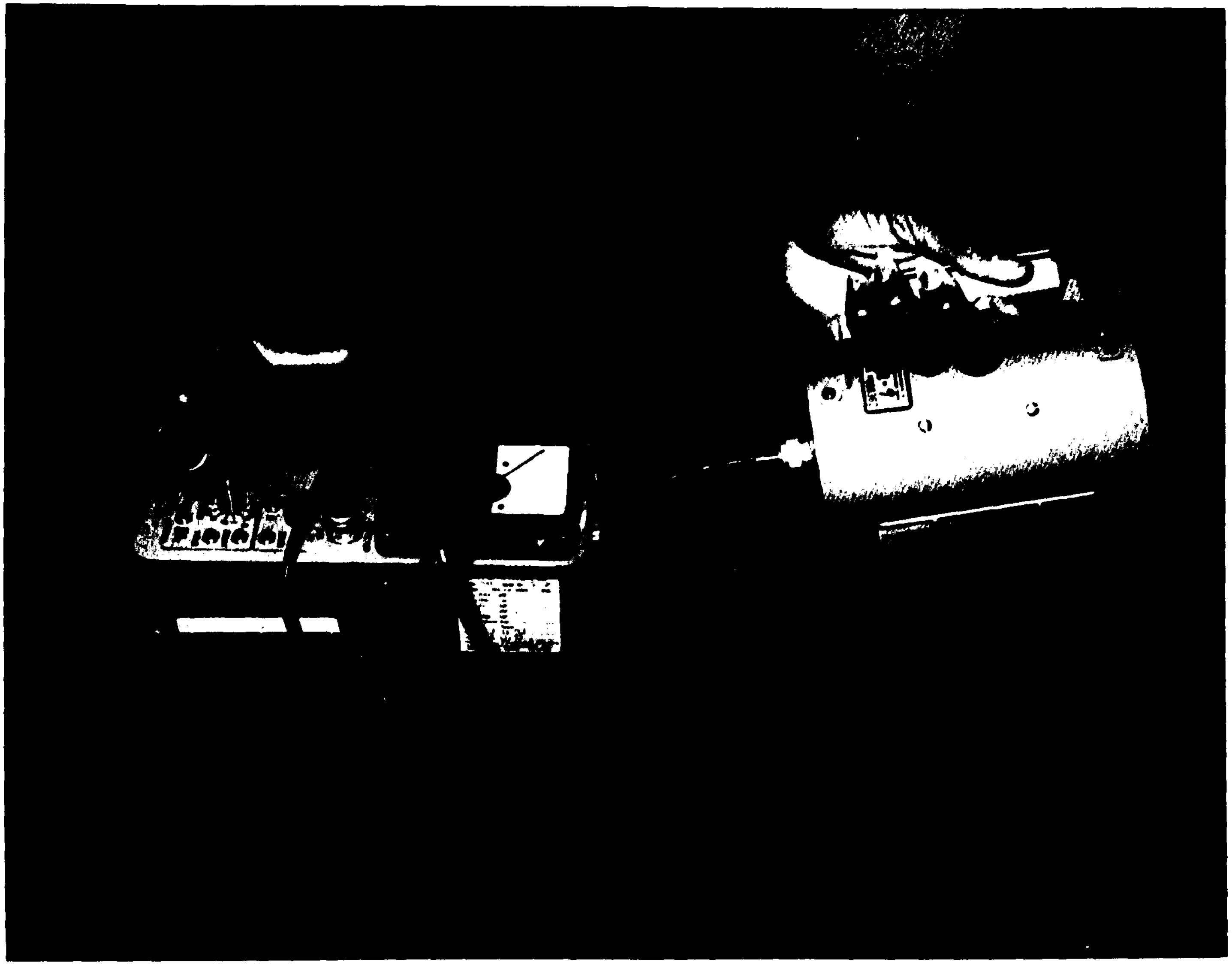

Figure 2–4. Ludlum Model 42–9 neutron detector.

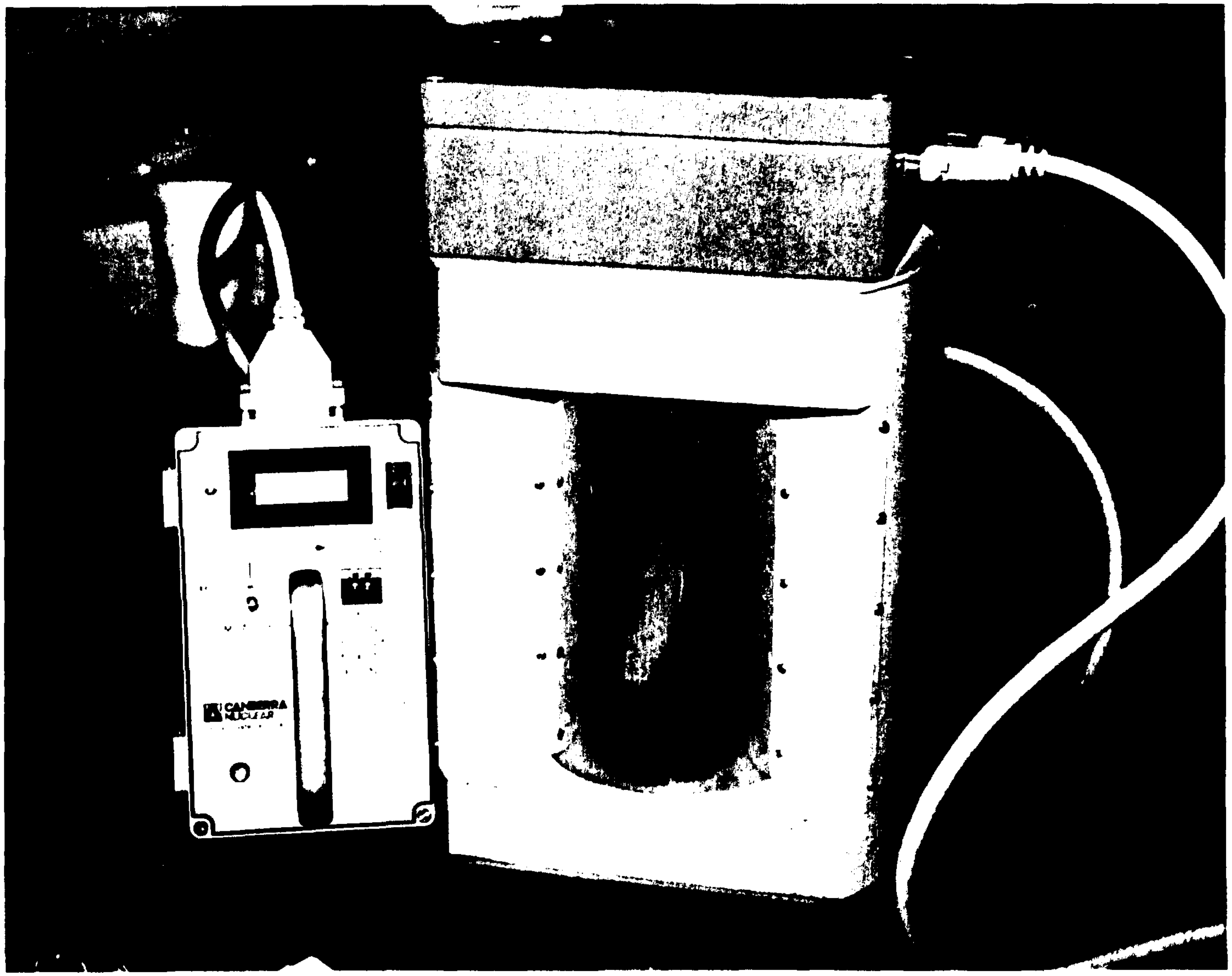

Figure 2–5. Jomar Model JSP–12 neutron detector.

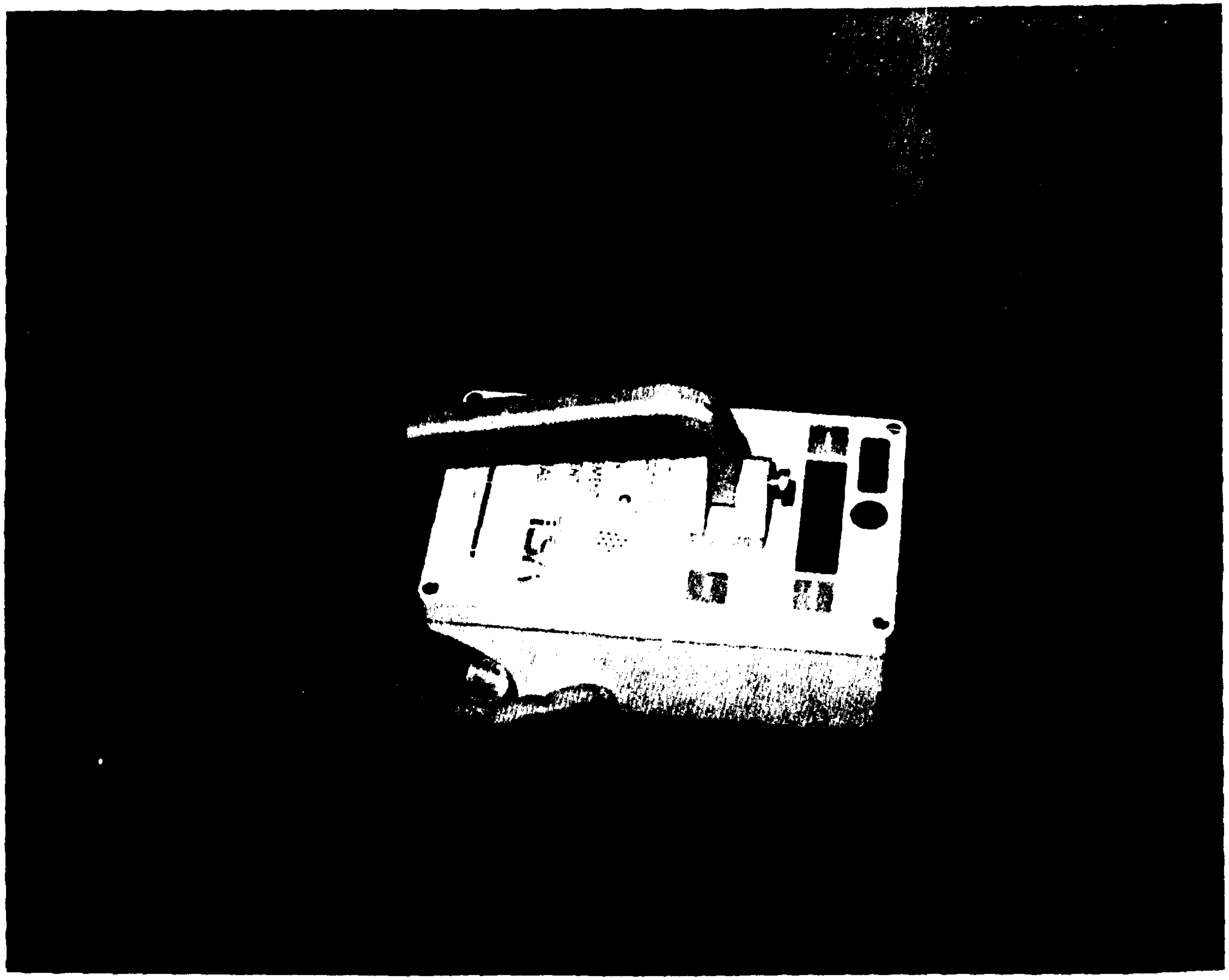

Figure 2–6. TSA NNV–470As neutron detectors.

Figure 2–7. Bubble dosimeters.

It should be noted that the bubble dosimeter is an unmoderated, passive device and can be read by visually counting the bubbles that are formed by the neutron interactions. The remaining instruments all utilize a nuclear reaction that has a peak response to thermal neutrons. Thus, all of the remaining instruments, except the TSA NNV-470As, surrounds the detector element with a thickness of polyethylene to moderate the incident fast neutrons and are used primarily for health physics purposes. The TSA NNV-470As is a special purpose instrument and was intentionally designed without a moderator.

It should also be noted that, since the instruments were borrowed, some of the electronics associated with each detector did not provide a digital readout that would have been preferred for the test. In particular, the Ludlum Model 15 and the Ludlum Model 42-9 contained electronic analog readout devices that required the individual performing the measurement to interpret a vibrating needle on a scale that was labelled in either mrem/hr or 1000s of counts/minute. The interpretation of the needle position introduced some uncertainty that would not be present with a digital readout device. Further, a transformation of the analog data was necessary in order to provide results that could be used on a comparative basis. This transformation is described in detail in paragraph 2.6.1. Finally, the TSA NNV-470As had a built-in preset counting interval of 20 seconds, therefore, additional readings were taken to provide comparable statistics as those associated with the other instrument readings.

2.4 TEST GEOMETRY.

Figure 2-8 shows the test geometry for the unmoderated neutron source exposures. The neutron source was positioned approximately one meter above the hangar floor in a thin-walled aluminum can. The RDE were positioned on relatively lightweight aluminum and steel aircraft maintenance platforms with each instrument located at one meter from the source. Figure 2-9 shows the same geometry for the moderated neutron source exposures. Background and gamma-ray sensitivity measurements were made in the same geometry without the neutron source present and with the ^{60}Co source replacing the neutron source, respectively.

The radial measurements (Figure 2-10) were made by measuring and marking measurement locations on the hangar floor, affixing an RDE to a step on a stepladder at the proper height above the floor, and using a plumb bob to assure positive positioning of the detector.

2.5 TEST PROCEDURES.

Multiple readings of each instrument were made at each measurement location. Those instruments that were equipped with the analog meters were read by an individual, who then left the area, returned to the instrument after a few minutes, and reread the instrument. This approach eliminated a fixed meter image in an individual's mind and provided independent readings. The

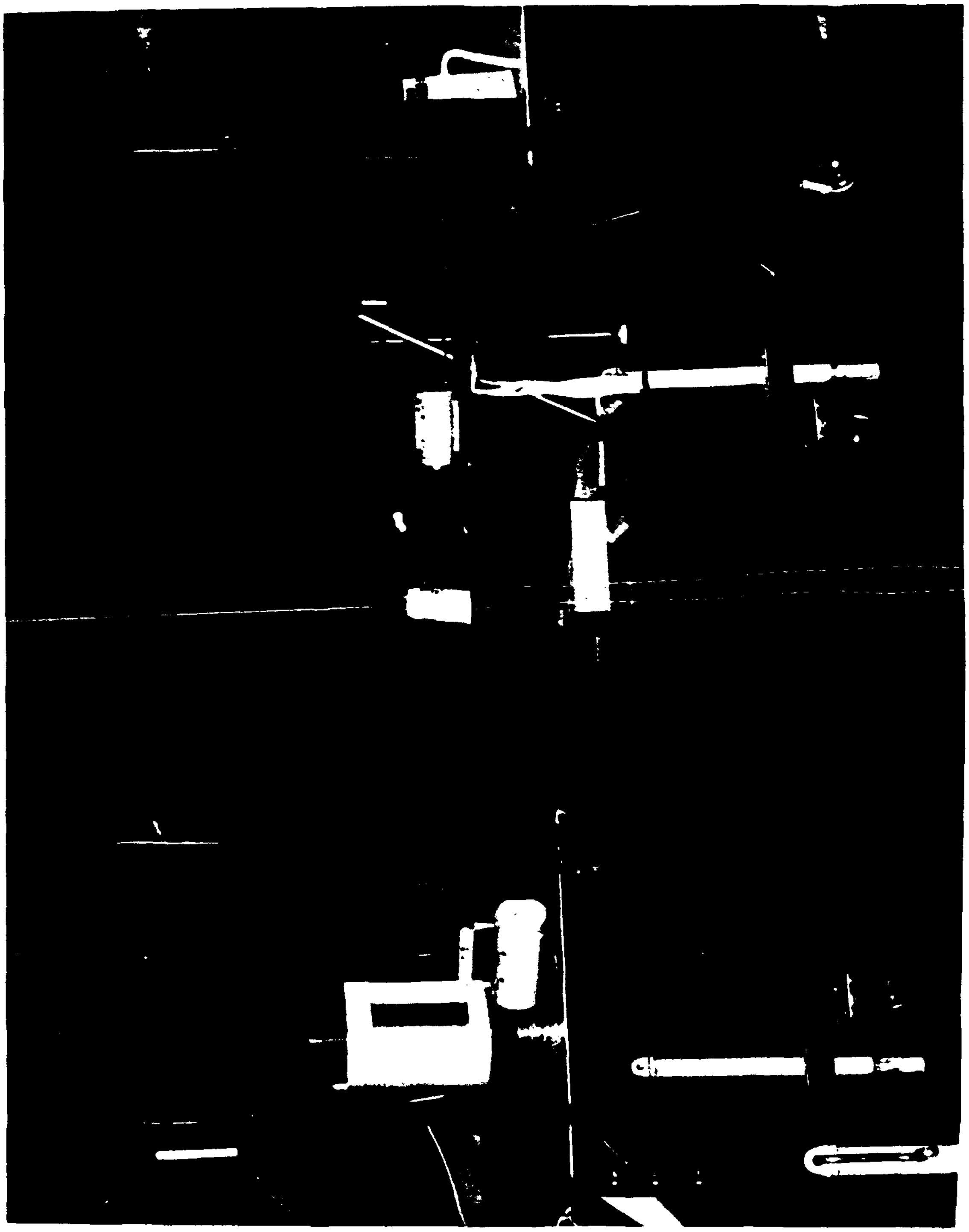

Figure 2–8. Test geometry with unmoderated source.

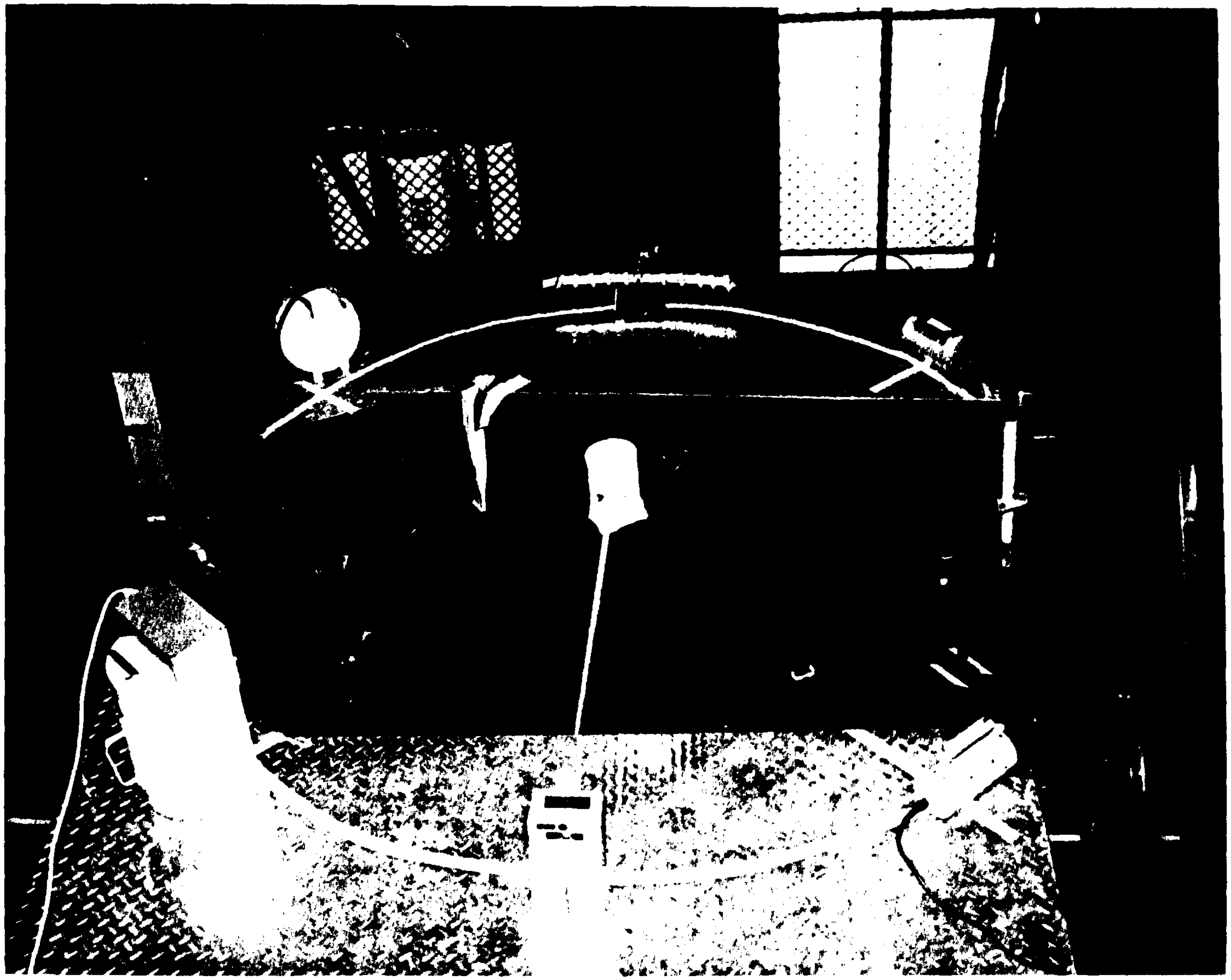

Figure 2–9. Test geometry with moderated source.

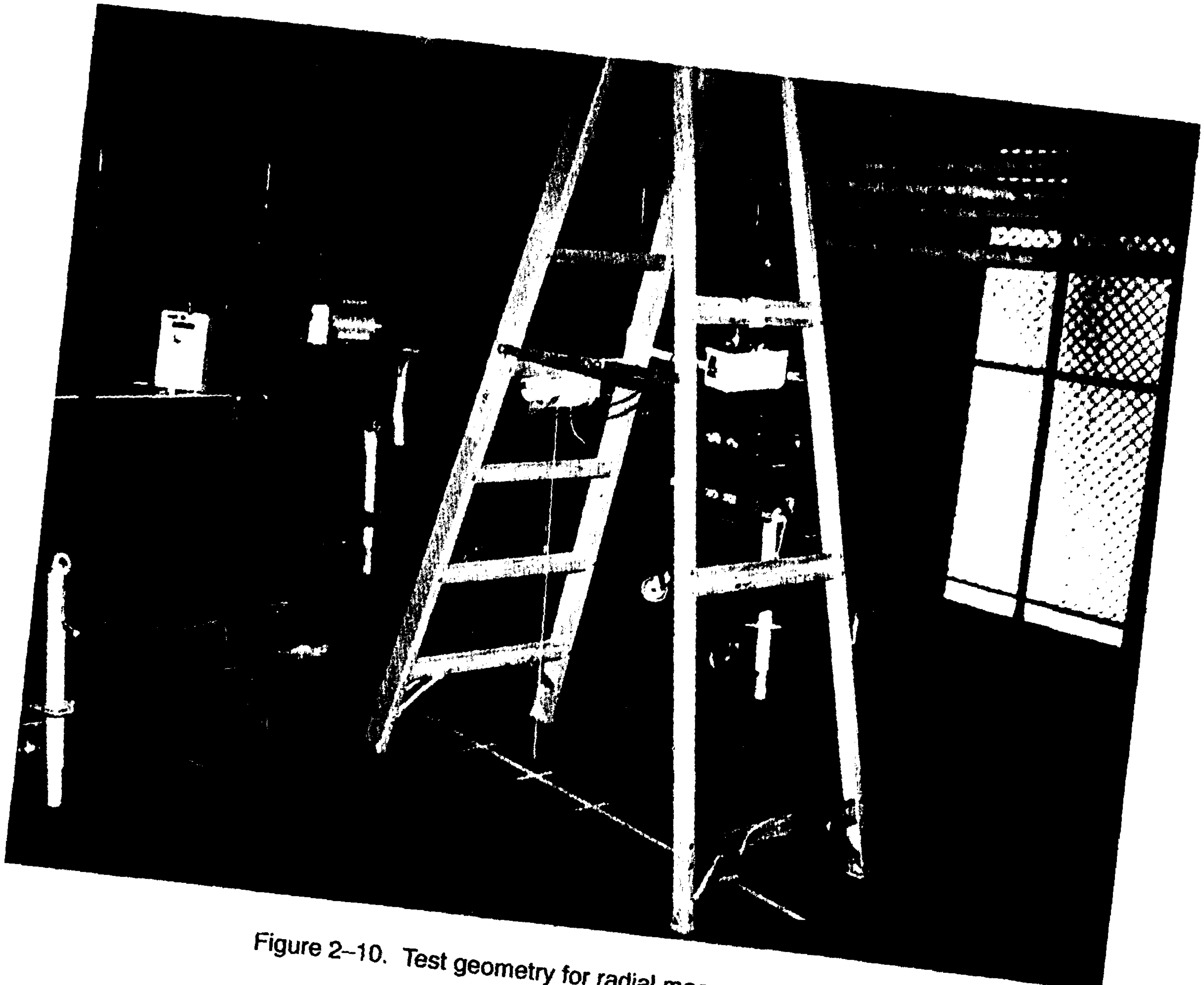

Figure 2–10. Test geometry for radial measurements.

procedure was repeated at least three times for each instrument and measurement position. Since there were a number of differentindividuals supporting the tests, instrument assignments were varied in an attempt to minimize individual induced bias in the readings. Of course, for the digital readouts the actual number of counts displayed for the preset accumulation time, typically 100 seconds, was recorded; except the TSA NNV-470As, which had a built-in preset recording time of 20 seconds.

2.6 DATA ANALYSIS.

2.6.1 Analog to Digital Transformation.

The Ludlum Model 12-4 had an analog display scaled in units of mrem/hr. Using Table 2-2, the appropriate analog-to-digital transformations were performed.

Table 2-2. Neutron flux dose equivalents.

Neutron Energy (Mev)	Number of neutrons per cm^2 equivalent to a dose of 1 rem (neutron/cm^2)
Thermal	970×10^6
0.0001	720×10^6
0.005	820×10^6
0.02	400×10^6
0.1	120×10^6
0.5	43×10^6
1.0	26×10^6
2.5	29×10^6
5.0	26×10^6
7.5	24×10^6
10	20×10^6
10 to 30	14×10^6

1 This table was extracted from a table provided by Ludlum Measurements, Inc.

If it is assumed that the moderated ^{252}Cf source corresponds to a neutron energy of approximately 0.5 Mev, the neutron flux dose equivalent to 1 mrem/hr can then be calculated using the data in Table 2-2. Note that the conversion factor is given in rem and our data are recorded in mrem/hr. For a given moderated source measurement, the following calculation was performed to obtain the proper units (i.e., for comparison with other instruments, counts per second):

$$(\textit{Measurement in mrem/hr}) \times (43 \times 10^3\ n/cm^2/mrem) \times \frac{1\ hr}{3600\ s}$$

Similarly, unmoderated source measurement transformations were performed using an assumed 2.0 Mev for neutron energy and interpolating the data in Table 2-2 to get:

$$(\textit{Measurement in mrem/hr}) \times (28 \times 10^3 \ n/cm^2/mrem) \times \frac{1\ hr}{3600\ s}$$

The Ludlum Model 15 also had an analog meter, however, as noted in Section 2.1.3, the meter was scaled for thousands of counts per minute (rather than mrem/hr). Although not quantified in the data analyses, analog readings introduced additional uncertainty in the tests using these detectors.

2.6.2 Data Processing.

Recorded counts using each of the detectors (both analog and digital types of meters) were converted to a common count rate of counts per second in the data analysis. Average count rates were then computed.

2.6.3 Uncertainty Analysis.

Uncertainty analysis was performed for presenting comparative results and estimating LASF performance for each detector. Uncertainty factors were calculated incorporating:

- Uncertainty associated with the source strength

  Given:[1] *Factor = 0.15 of source strength*

- Uncertainty associated with a single recorded count

  Calculated: $\textit{Factor} = \dfrac{(\textit{recorded count rate})^{1/2}}{\textit{recorded count rate}}$

- Uncertainty associated with an average of multiple recorded counts

  Calculated: $\textit{Factor} = \dfrac{(\textit{standard deviation})}{\textit{average count rate}}$

2.7 RESULTS AND DISCUSSION.

The following sections contain summary tables of the data gathered at Andrews Air Force Base. A complete listing of all data obtained is contained in Appendix C.

2.7.1 Background Measurements.

Table 2-3 is a summary of the background results; not all detectors were available when the primary background measurements were made. The results indicate a very low background and when

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[1] *This uncertainty factor was obtained from a data sheet provided by the supplier of the ^{252}Cf source.*

compared with the count rates of the detectors when exposed to the neutron sources, the background can be ignored.

Table 2-3. Background measurement summary.

Detector	Average Counts Per Second (cps)	Number of Measurements (n)
Ludlum Model 15	0.35	11
TSA NNV-470As	0.03	16
Ludlum Model 12-4	1	1
Jomar Model JSP-12	1	1
Ludlum Model 42-9	1	1
INF	0.96	6

1 Detector not available at time background measurements were taken.

2.7.2 Gamma-Ray Sensitivity Measurements.

Table 2-4 contains the results of the detectors exposed to the ^{60}Co gamma-ray source. These results indicate count rates comparable to the background count rates, therefore the detectors are not responding to gamma-rays. Thus, these data were used to represent background for those detectors that were not available for the initial background measurements.

Table 2-4. Gamma-ray measurement summary.

Detector	Counts Per Second (cps)
Ludlum Model 15	1.03
TSA NNV-470As	0.10
Ludlum Model 12-4	0.00
Jomar Model JSP-12	0.16
Ludlum Model 42-9	0.00
INF	1

1 The count rates presented in Table 2-4 are based on a single measurement for each detector. Although unavailable for this set of measurements, the INF detector was previously tested by the Sandia National Laboratory (SNL) and demonstrated gamma-ray insensitivity.

2.7.3 Radial Measurements.

The purpose of the radial measurements was to assure that there were no large deviations from the expected behavior of the neutron radiation field in the vicinity where the comparative evaluation measurements would be made. Ideally, it is expected that the radiation field will decrease with distance in accordance with the inverse square law. However, since the measurements were not made in a vacuum with a perfect source or with perfect detectors, the radial measurement of the radiation field is not expected to be exact. Only the Ludlum Model 15 and INF detector were used for the radial measurement since the goal was to assess the radiation field and not to evaluate the detectors.

Table 2-5 lists the results of the radial measurements, and the last column contains results normalized to the one meter distance measurement (Note: the value of k in Table 2-5 would be constant for the ideal case). It can be seen that the adjacent measurements deviate from the one meter measurement by no more than twenty percent; this is an acceptable result and there is no evidence of large (factor of 2) deviations from the ideal behavior.

Table 2-5. Radial measurement summary.

Detector (Source Moderation)	r[1] (cm)	Average cps[2]	n[3]	k[4]	k/k_{100}
Ludlum Model 15 (Unmoderated)	32.5	62.6	9	6.61×10^4	0.82
	50.0	27.5	9	6.87×10^4	0.85
	75.0	12.5	9	7.01×10^4	0.87
	100	8.09	9	8.09×10^4	1.00
	125	5.31	9	8.30×10^4	1.03
	150	4.46	9	1.00×10^5	1.24
	200	2.47	9	9.87×10^4	1.22
INF (Unmoderated)	75	1000	3	5.63×10^6	0.85
	100	663	3	6.63×10^6	1.00
	150	352	3	7.92×10^6	1.19
	200	227	3	9.08×10^6	1.37
Ludlum Model 15 (Moderated)	50.0	31.7	3	7.93×10^4	0.86
	75.0	16.1	3	9.06×10^4	0.98
	77.0	15.3	3	9.07×10^4	0.98
	100	9.22	6	9.22×10^4	1.00
	125	6.53	6	1.02×10^5	1.11
	150	4.83	6	1.09×10^5	1.18
	200	2.83	3	1.13×10^5	1.23

[1] r is distance of detector from the source
[2] cps is counts per second
[3] n is the number of measurements.
[4] k is the product of average cps and r^2.

2.7.4 Measurement Position Sensitivity.

As previously stated, the detectors were placed one meter from the neutron source. Simultaneous measurements could be made along this arc with detector separation distances of approximately 85 centimeters (see Figure 2-11). To assure that such separation distances were adequate to prevent neutron scatter from one detector into an adjacent detector, the detectors were exposed at each of the arc locations with different neighboring detectors. The results of these measurements for both unmoderated and moderated sources are summarized in Tables 2-6 and 2-7 respectively. The positions labeled A through F in the following tables refer to locations identified on Figure 2-11.

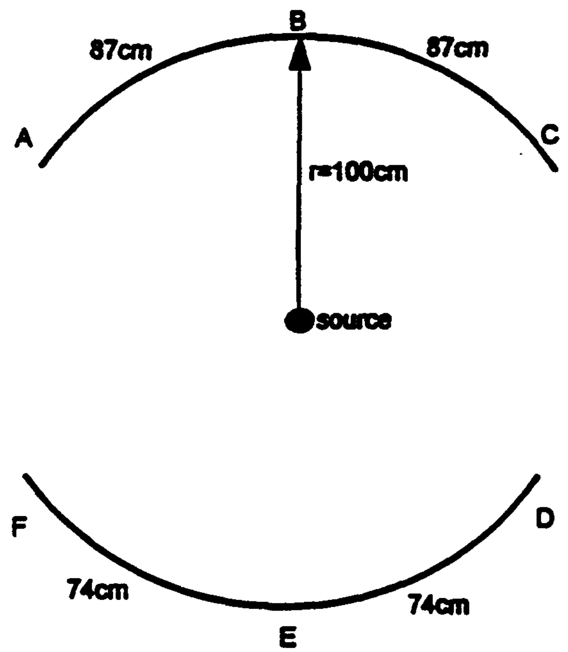


Figure 2-11. Position sensitivity test geometry.

Table 2-6. Position sensitivity with an unmoderated source.

Position Detector	A	B	C	D	E	F	Overall Average
	Average Counts Per Second (number of measurements)						
Ludlum Model 15	5.8 (3)	6.6 (6)	8.9 (6)	6.7 (3)	6.7 (3)	6.1 (6)	6.8 (27)
TSA NNV-470As	4.3 (6)	4.7 (3)	4.9 (6)	4.7 (6)	4.4 (3)	4.5 (3)	4.6 (27)
Ludlum Model 12-4	13 (3)	12 (3)	13 (3)	13 (4)	13 (3)	13 (3)	13 (19)
Jomar Model JSP-12	(1)	(1)	(1)	320 (3)	310 (3)	320 (3)	320 (9)
Ludlum Model 42-9	2.1 (3)	(1)	(1)	2.4 (3)	(1)	2.2 (3)	2.2 (9)
Bubble Dosimeter	(1)	0.02 (10)	(1)	(1)	0.02 (10)	(1)	0.02 (20)
INF	.2						2

1 No measurement
2 Detector not available

Table 2-7. Position sensitivity with a moderated source.

Detector/Position	A	B	C	D	E	F	Overall Average
	Average Counts Per Second (number of measurements)						
Ludlum Model 15	9.0 (6)	9.1 (6)	9.1 (6)	8.4 (6)	9.3 (6)	9.4 (6)	9.1 (36)
TSA NNV-470As	18 (6)	19 (6)	20 (6)	18 (6)	19 (6)	19 (6)	19 (36)
Ludlum Model 12-4	13 (7)	14 (6)	16 (6)	13 (6)	14 (6)	14 (6)	14 (37)
Jomar Model JSP-12	290 (6)	290 (6)	280 (6)	270 (6)	280 (6)	280 (6)	280 (36)
Ludlum Model 42-9	3.5 (6)	3.4 (6)	3.1 (6)	3.5 (6)	3.1 (6)	3.6 (6)	3.4 (36)
Bubble Dosimeter	0.02 (10)	0.02 (10)	(1)	(1)	(1)	(1)	0.02 (20)
INF	2						2

1 No measurement
2 Detector not available

It is clear from these tables that there is no measurable effect of arc location on the results of any particular detector. This result permits the pooling of all one-meter distance measurements for the purpose of doing the comparative evaluation.

2.7.5 Comparative Evaluation.

Tables 2-8 and 2-9 contain the summary results of the measurements made at one meter from the unmoderated and moderated sources, respectively. It is evident that the bubble dosimeter is highly insensitive and those detectors with the largest sensitive area have the larger count rates. It is also evident that the TSA NNV-470As detector, with no inherent moderation, has a larger count rate for the moderated neutron source. Also, except for the Jomar JSP-12 detector which is heavily moderated, the remaining detectors show only a modest change in the count rate between the unmoderated and moderated neutron source. All of these results are consistent with expectations. The efficiency in column 4 is expressed as counts per second per neutron per second (cps/nps).

Table 2-8. Summary of 1m results with unmoderated source.

Detector	Average cps	n	Efficiency cps/nps	Uncertainty Factor
Ludlum Model 15	7.44	36	3.72×10^{-6}	0.21
TSA NNV-470As	4.60	27	2.30×10^{-6}	0.18
INF	663	3	3.32×10^{-4}	0.15
Ludlum Model 12-4	13.0	19	6.51×10^{-6}	0.17
Jomar Model JSP-12	322	9	1.61×10^{-4}	0.15
Ludlum Model 42-9	2.21	9	1.10×10^{-6}	0.18
Bubble Dosimeter	0.0190	20	9.52×10^{-9}	0.35

Table 2-9. Summary of 1m results with moderated source.

Detector	Average cps	n	Efficiency cps/nps	Uncertainty Factor
Ludlum Model 15	9.08	42	4.54×10^{-6}	0.17
TSA NNV-470As	18.7	36	9.35×10^{-6}	0.16
INF	1209	12	6.05×10^{-4}	0.15
Ludlum Model 12-4	13.9	37	6.96×10^{-6}	0.23
Jomar Model JSP-12	285	18	1.42×10^{-4}	0.15
Ludlum Model 42-9	3.38	18	1.69×10^{-6}	0.20
Bubble Dosimeter	0.0177	20	8.86×10^{-9}	0.49

Since the purpose of the tests was to permit selection of detectors for further evaluation at the Los Alamos Simulation Facility, the following procedure was used to estimate performance at LASF:

(1) A relative efficiency factor was calculated for each detector based on the results of the moderated neutron source measurements at one meter distance. The assumption was made that

the energy distribution of the neutrons from the moderated ^{252}Cf was a reasonable representation of the energy spectrum from an Am(Li) neutron source. This is probably not a very good assumption but the moderated source spectrum is certainly closer to the Am(Li) spectrum than the unmoderated source spectrum. The factor was calculated by dividing the count rate of each detector by the ^{252}Cf source strength to give the number of counts per second per unit source strength.

(2) The efficiency factor was multiplied by the Am(Li) source strength (1750 n/s) expected from the LASF source to give an expected net count rate.

(3) The count rate was multiplied by 100 to provide an estimate of the number of expected counts in a 100 second counting interval.

(4) An uncertainty in the estimated counts per 100 seconds was calculated by taking the square root of the estimate and combining that through the root-mean-square procedure with the uncertainties of the Andrews source strength and detector measurements.

Table 2-10 summarizes the expected results at LASF with the associated uncertainty.

Table 2-10. Expected results at LASF.

Detector	Counts per 100s	Uncertainty Factor
Ludlum Model 15	0.79	1.14
TSA NNV-470As	1.64	0.80
INF	106	0.18
Ludlum Model 12-4	1.22	0.93
Jomar Model JSP-12	24.9	0.25
Ludlum Model 42-9	0.30	1.85
Bubble Dosimeter	0.002	25.4

2.8 SUMMARY.

The opportunity to expose various portable, commercially available neutron detectors to the ^{252}Cf neutron source at Andrews AFB provided valuable data that permitted an informed selection of detectors to test further at the Los Alamos Simulation Facility. The results presented in Table 2-10 clearly indicate that the bubble dosimeter is much less sensitive than any of the other detectors. Also, it is clear that the INF and Jomar Model JSP-12 are the most sensitive detectors. The TSA NNV-470As and the three Ludlum detectors are at best marginal. However, the results are calculated for a counting time of 100 seconds and a measurement distance of one meter; changing these parameters to twice the counting time and one-half the measurement distance increases the accumulated counts by a factor of eight. Thus, these four detectors become worthy of additional testing.

The detectors recommended for testing at the Los Alamos Simulation Facility were: (1) INF, (2) Jomar Model JSP-12, (3) TSA NNV- 470As, (4) Ludlum Model 12-4, and (5) Ludlum Model 42-9.

It should be noted that the only difference between the Ludlum Model 42-9 and the Ludlum Model 15 is the Ludlum Model 42-9 is equipped with a digital readout which is the preferred readout device. Thus, the Ludlum Model 42-9 is the choice for additional testing even though the Ludlum Model 15 appears to have the greater sensitivity; this may be due to the tendency to interpret the analog indicator on the high side plus the additional uncertainty introduced by the necessary conversion of mrem/hr to counts per second.

SECTION 3

PHASE 2 - LASF TESTS

3.1 OVERVIEW.

The LASF is located at Technical Area 18 (TA-18) of the Los Alamos National Laboratory. The LASF is a large Butler-type building with thin metal walls and a thin metal floor in a major portion of the building that provides, essentially, a "zero-scatter" environment for neutron sources. Neutron sources used were of two types: (1) calibration and (2) "special". The calibration sources were ^{252}Cf and two Am(Li) sources of different strengths. Two "special" sources (see classified companion report) were also used. Measurements were made with four different neutron detectors at separation distances from the source ranging from 50 centimeters to two meters. Measurements were also made with shielding materials of cadmium, wood, polyethylene, and borated polyethylene placed between the source and detector.

The following paragraphs provide additional details about the various tests conducted at LASF.

3.2 NEUTRON SOURCES.

3.2.1 Calibration Sources.

The ^{252}Cf source strength was 1.80×10^6 neutrons per second, calibrated on 25 July 1990 to an uncertainty of 1.65 percent. Source strength at the time of the measurements was 5.88×10^5 neutrons per second. The two Am(Li) sources emitted 1.75×10^3 and 4.9×10^5 neutrons per second, respectively. They will be referred to as the "weak" and "strong" Am(Li) sources, respectively. These three sources are "point" sources.

3.2.2 "Special" Sources.

The "special" neutron sources are described in Volume 2 of this report.

3.3 RADIATION DETECTION EQUIPMENT.

Five detectors were recommended as a result of the Phase I tests. However, a Ludlum Model 12-4 was not available for testing at LASF, therefore only the following four neutron detectors were included in the test: (1) the INF detector, (2) the Jomar Model JSP-12, (3) the Ludlum 42-9, and (4) the TSA NNV-470As. Table 2-1 summarizes the important features of these detectors. Descriptive literature on the detectors is contained in Appendix B. These instruments are depicted in Figures 2-1, 2-5, 2-4, and 2-6, respectively.

It should be noted that all of these detectors were equipped with digital readout. The INF detector had a built-in 100-second counting time and the TSA NNV-470As had a 20-second built-in counting time. The Jomar Model JSP-12 had an adjustable counting time, which, for these tests was set at 100 seconds. The Ludlum 42-9 with the Model 2221 scaler had adjustable counting times ranging from 0.1 minutes to ten minutes; it was set at two minutes for these tests.

3.4 TEST GEOMETRY.

Figure 3-1 shows the test geometry for the calibration source with the four neutron detectors arranged on the quadrant template provided by the LASF staff. All measurements with the calibration sources were made using this template for separation distances of one meter or less. Selected radial lines were extended beyond the template to provide separation distances up to two meters. A similar arrangement included various quantities of shielding materials inserted between the source and detectors.

Figure 3-2 is representative of the geometry of the tests with the "special" sources. This figure displays the detectors located at one meter from the centerline of the source with two inches of polyethylene between the source and detectors. Also, detectors were interchanged, at the one meter separation distance, among the positions to determine if measurement symmetry was achieved in either the axial or azimuthal directions.

3.5 TEST PROCEDURES.

Multiple readings of each instrument were made at each measurement location. The TSA NNV-470As was read several times at each location, while the remaining instruments were read a minimum of three times at each location. The background measurements were made in the typical measurement geometry with the neutron sources removed.

The shielding materials consisted of 1.6mm-thick cadmium sheets, 0.635cm- and 1.905cm-thick pieces of plywood, 2.54cm- and 5.08cm-thick slabs of polyethylene, and 5.08cm-thick borated (5% by weight of natural boron) polyethylene bricks. These were arranged singly and in combination between the Am(Li) neutron sources and each detector.

Measurements were made of the "special" sources with no shielding material and with a 5.08cm-thick slab of polyethylene adjacent to the source and detectors at one- and two-meter separation distance. A measurement was also made at a 50-centimeter separation distance with no shielding material.

3.6 DATA ANALYSIS.

3.6.1 Data Processing.

Recorded counts using each of the detectors were converted to a common count rate of counts per second. Average count rates were then computed.

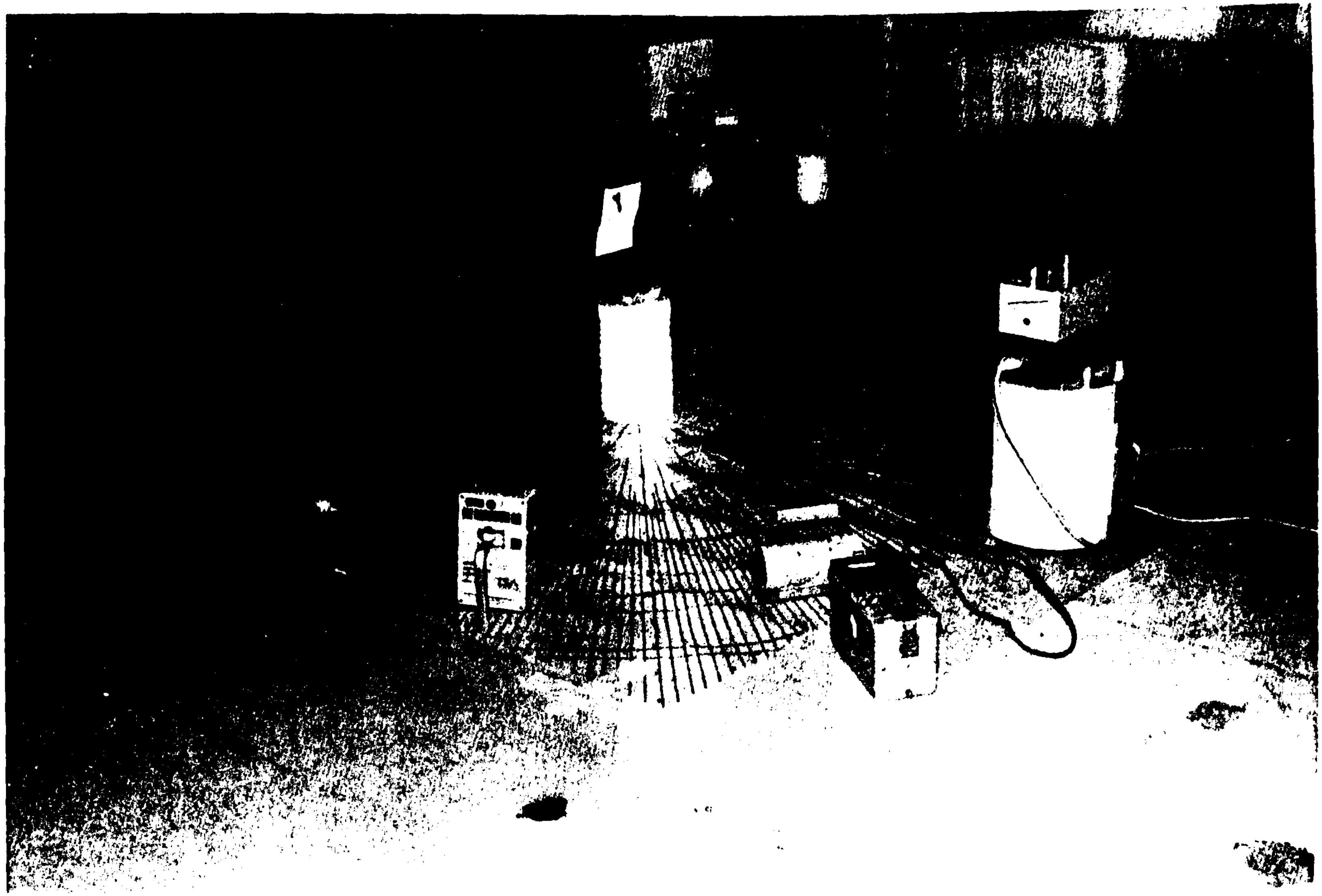


Figure 3–1. Test geometry for calibration source measurements.

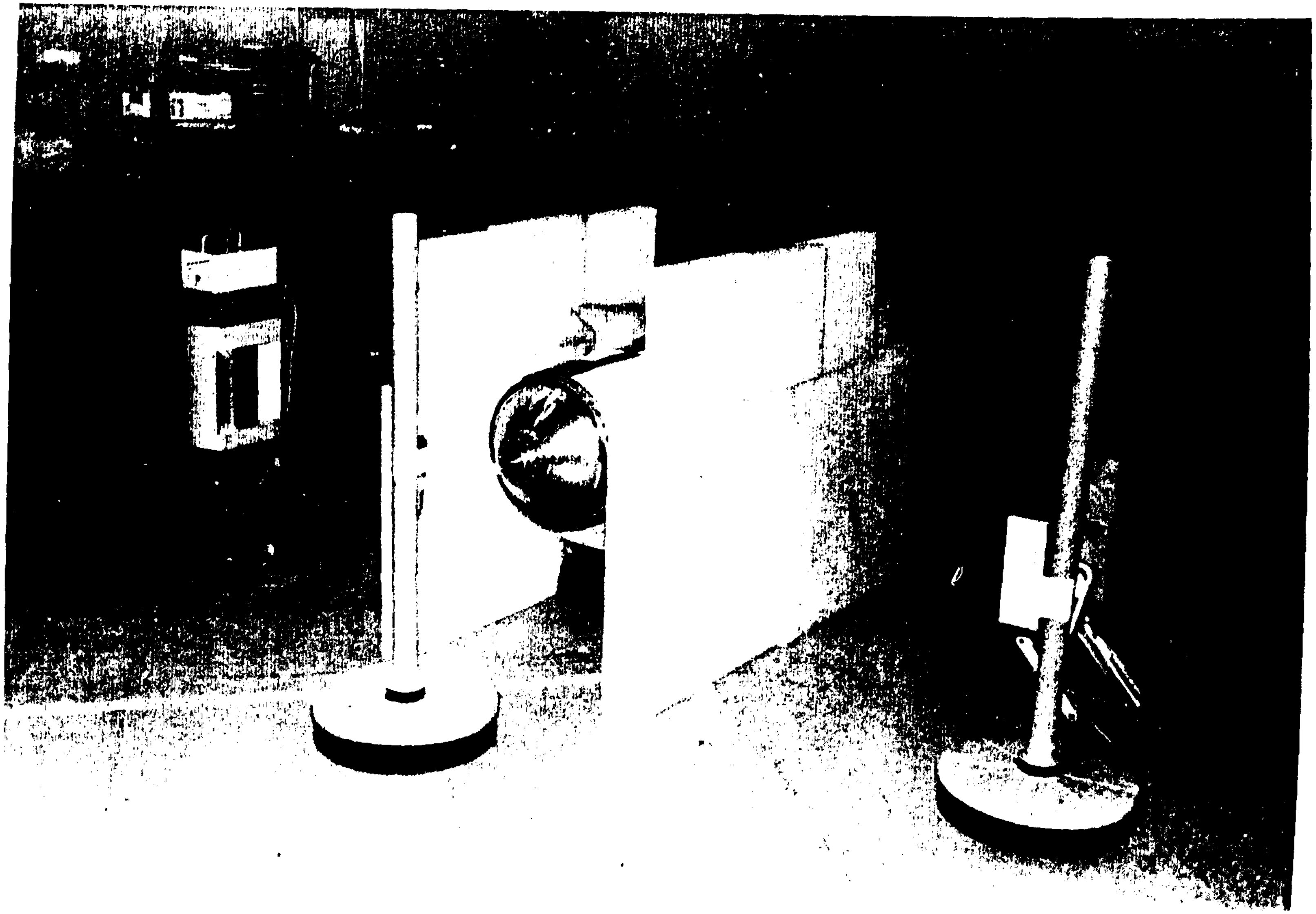


Figure 3–2. Test geometry for “special” source measurements.

3.6.2 Uncertainty Analysis.

Uncertainty analysis was performed for presenting comparative results. However, since the background level was significantly higher at LASF than in the AAFB tests (see Section 3.7.1), analyses were performed to address varying background levels. For example, in tests which were repeated at different times of the day (i.e., using the same source and test configuration) average *net* counts per second were computed to reflect recorded or "total" counts minus the background counts.

For example, in a case where measurements were taken in the morning at one background level, net counts were computed; similarly, for afternoon data collection at a different background level (but for the same type of test) net counts were also computed. Next, an average of both morning and afternoon net counts was calculated and the uncertainty, i.e., the standard deviation of the net counts was determined. (Note: For those tests conducted one time only, total counts were averaged and a single average background value was subtracted from that total to determine the net count value.)

3.7 RESULTS & DISCUSSION.

The following sections contain summary tables of the data obtained during the tests at the Los Alamos Simulation Facility. A compilation of all the data obtained from the calibration sources is presented in Appendix D.

3.7.1 Background Measurements.

Background measurements were taken several times throughout the duration of the test period. A summary of the background measurement results is contained in Table 3-1. It should be noted that these background results are considerably greater, especially for the more sensitive instruments such as the INF and Jomar Model JSP-12, than similar results from the Andrews AFB tests. Also, as can be seen from the data in Table 3-1, the background changed significantly during the test period; as neutron sources were introduced into the LASF, although displaced by 15 meters or more from the measurement location, they apparently still contributed to the background. Again, this is more pronounced for the more sensitive detectors.

Since the background is significant, especially for those measurements with the "weak" Am(Li) neutron source and for the measurements with significant thicknesses of shielding material, the background was subtracted from all measurements. The average background for each detector resulting from the background measurements closest in time to particular source measurements was used as the appropriate background for those measurements.

Table 3-1. Background measurements.

TSA NNV-470As (20s)			Ludium 42-9 (120s)			Jomar JSP-12 (100s)			INF (100s)			
Date and Time	Average Recorded Counts	n	Date and Time	Average Recorded Counts	n	Date and Time	Average Recorded Counts	n	Date and Time	Average Recorded Counts	n	Comments
3-30-93 0900	2.03	37	3-30-93 0915	0.50	2	3-30-93 0900	37.0	6	3-30-93 0945	237	6	
1550	1.00	4	1550	1.00	1	1440	41.6	9	1315	368	10	
3-31-93 0905	2.00	10	3-31-93 0905	2.00	3	3-31-93 0905	50.0	3	3-31-93 0905	380	3	
									1233	230	2	
1330	3.00	2	1330	3.50	2	1330	73.0	2	1330	686	1	
4-1-93 0900	3.75	12	4-1-93 0900	5.33	3	4-1-93 0900	103	3	4-1-93 0900	875	5	All sources 15m from test area
									1030	374	1	Suspect, not used
1315	3.69	13	1315	4.00	4	1315	88.3	4	1315	957	7	All sources 15m from test area

(1) n=number of measurements used to calculate the average background.

3.7.2 Calibration Source Measurements.

3.7.2.1 ^{252}Cf Measurements. Measurements were made with a calibrated ^{252}Cf source to provide a tie point to the Andrews AFB measurements. The results of these measurements are presented in Table 3-2. The calculated efficiencies contained in Table 3-2 agree favorably with similar calculations for Andrews AFB measurements (Table 2-7) when the large uncertainty in the Andrews AFB ^{252}Cf source is considered.

Table 3-2. Unshielded calibration source measurement summary.
^{252}Cf at 1m

Detector	Average Total cps	Average Background (BG) cps	Average Net cps (Total - BG)	Efficiency (cps/nps)
TSA NNV-470As	1.58	0.150	1.43	2.60×10^{-6}
Ludlum Model 42-9	0.767	0.0292	0.738	1.21×10^{-6}
Jomar Model JSP-12	129	0.730	128	2.18×10^{-4}
INF	270	6.86	263	4.47×10^{-4}

Table 3-3 presents the results of the inverse square law measurements that were performed with the ^{252}Cf. These results are similar to those obtained at Andrews AFB (see Table 2-5) and there is no evidence of unusual behavior in the neutron environment.

Table 3-3. Radial measurement summary for INF neutron detector.

r (cm)	Net cps = (Total Recorded Counts - Background) / 100s Background = 384 Counts	k (Net cps x r^2)	k/k_{100}
50	71.7	1.79×10^5	0.796
75	36.4	2.05×10^5	0.909
100	22.5	2.25×10^5	1.00
125	14.6	2.28×10^5	1.01
150	10.8	2.42×10^5	1.08
200	6.61	2.64×10^5	1.17

3.7.2.2 Am(Li) Measurements - Unshielded Source. Table 3-4 presents the summary results of the measurements made at one meter distance from the unshielded weak Am(Li) source. The comparison of the measured net counts in 100 seconds for the weak Am(Li) source with the expected counts in 100 seconds predicted from the moderated ^{252}Cf measurements at Andrews AFB (see Table 2-9) indicate that for the INF and Jomar Model JSP-12 detectors the measurements were greater than predicted by approximately 50 percent. This is not an unreasonable agreement since the moderated ^{252}Cf source is not representative of the Am(Li) neutron energy distribution. Results from the TSA NNV-470As and Ludlum Model 42-9 were not statistically different from background, thus no meaningful comparison of the measured and predicted results can be made.

Table 3-4. "Weak" Am(Li) measurement summary 1m from unshielded source.

Detector	Average Counts per 100s	Uncertainty
TSA NNV-470As	(1)	N/A
Ludlum Model 42-9	(1)	N/A
Jomar Model JSP-12	41.0	9.2%
INF	143	10%

1 Not statistically different than background.

Table 3-5 contains detector efficiencies at one meter distances calculated from the measurements of the "weak" and "strong" Am(Li) sources. Table 3-6 contains similar information for a one-half meter measurement distance. Only the Ludlum Model 42-9 and TSA NNV-470As were exposed at the one-half meter distance since adequate statistics were obtained at the one meter distance with the other two detectors. It is emphasized that each calculated efficiency applies only to that detector at that measurement distance for that particular type source. Any change in measurement geometry or type of source will require calculation of the efficiency for that particular case. The efficiency factors can, however, be used to predict count rates as a function of source strength for the appropriate source type in a similar geometry.

Table 3-5. Detector efficiencies based on "weak" and "strong" Am(Li) 1m measurements.

Detector	Weak			Strong				
	Net cps	n	Eff (cps/nps)	Total cps	BG cps	Net cps	n	Eff (cps/nps)
TSA-NNV-470As	(1)	20	N/A	3.26	0.0625	3.20	5	6.53×10^{-6}
Ludlum Model 42-9	(1)	4	N/A	1.10	0.00833	1.09	3	2.23×10^{-6}
Jomar Model JSP-12	0.410	6	2.34×10^{-4}	113	0.307	113	3	2.31×10^{-4}
INF	1.43	5	8.17×10^{-4}	412	3.84	408	4	8.33×10^{-4}

1 Not statistically different than background.

Table 3-6. Detector efficiencies based on "Strong" Am(Li) 0.5m measurements.

Detector	Total cps	BG cps	Net cps	n	Eff (cps/nps)
TSA NVV-470As	10.9	0.095	10.8	10	2.20×10^{-5}
Ludlum Model 42-9	3.53	0.017	3.52	3	7.18×10^{-6}

The TSA NNV-470As and Ludlum Model 42-9 were exposed to the "weak" source at 0.5m, however, the counts recorded were not statistically different than background.

3.7.2.3 Am(Li) Measurements - Shielded Source. Table 3-7 contains a summary of the results of measurements of the "strong" Am(Li) source with various types and quantities of shielding materials placed between the source and detectors. The results are expressed in terms of a shielding factor (SF) which is the ratio of the net count rate with the shielding material in place to the net count rate with no shielding material. The materials were inserted between the source and detector in such a way as to assure that each detector was completely shielded by the material. Thus, the large area materials were inserted close to the detector while the small area materials were placed closer to the source. The measurements with the less sensitive instruments were made at a distance of one-half meter while the measurements with the more sensitive instruments were made at a distance of one meter.

Table 3-7. "Strong" shielded Am(Li) measurement summary.

Detector / Shielding	TSA NNV-470As Distance 0.5m		Ludlum Model 42-9 Distance 0.5m		Jomar Model JSP-12 Distance 1m		INF Distance 1m	
	Ave Net cps	SF	Ave Net cps	SF	Ave Net cps	SF	Ave Net cps	SF
None	10.8	N/A	3.51	N/A	113	N/A	409	N/A
2.54cm Wood	11.5	1.06	3.75	1.07	94.2	0.830	400	0.980
2.54cm Poly	15.3	1.42	2.91	0.830	51.9	0.460	259	0.630
5.08cm Poly	12.7	1.18	1.73	0.490	24.0	0.210	157	0.380
7.62cm Poly	7.62	0.706	0.663	0.190	(1)	(1)	(1)	(1)
10.2cm Poly	4.20	0.389	0.443	0.120	(1)	(1)	(1)	(1)
5.08cm B-Poly	6.72	0.594	1.73	0.490	36.7	0.320	137	0.330
10.2cm B-Poly	2.94	0.272	0.734	0.210	16.4	0.140	68.0	0.170
2.54cm Wood + 2.54cm Poly	(1)	(1)	(1)	(1)	40.3	0.360	231	0.560
2.54cm Wood + 5.08cm Poly	(1)	(1)	(1)	(1)	18.9	0.170	117	0.290
1.60mm Cd	(1)	(1)	(1)	(1)	115	1.00	404	0.990
1.60mm Cd + 2.54cm Poly	(1)	(1)	(1)	(1)	55.1	0.490	305	0.740
1.60mm Cd + 5.08cm Poly	(1)	(1)	(1)	(1)	24.5	0.220	157	0.380

1 No measurement

The results indicate the following:

(1) Except for the Jomar Model JSP-12, 2.5 cm of wood has very little effect on the measurement.

(2) 1.6 mm of cadmium has no effect on the measurement.

(3) The response of the TSA NNV-470As is enhanced by the addition, up to approximately 5 cm, of polyethylene; the same amount of polyethylene reduces the response of the other detectors.

(4) Except for the TSA NNV-470As and the Jomar Model JSP-12, there is no difference in response between equivalent thicknesses of borated polyethylene and non-borated polyethylene.

With the exception of the Jomar Model JSP-12 results for observation number (4), the results are as expected. The Jomar Model JSP-12 is inherently heavily moderated and contains sufficient cadmium shielding to exclude thermal neutrons not produced within the detector moderator, so the difference in response observed for 5 cm thicknesses of polyethylene and borated polyethylene is unexpected. A possible explanation is that the borated polyethylene was in the form of bricks which required that they be placed close to the source in order to subtend the entire solid angle of the detector. It is possible that the entire solid angle was not subtended by the brick which would explain the higher count rate observed for the borated polyethylene.

The enhanced response of the TSA NNV-470As with the introduction of moderating material between the source and detector was expected since that detector has no inherent moderator but yet requires thermal neutrons to produce counts in the detector (as do all the detectors). All the remaining detectors are designed with polyethylene moderation included to enhance the response to fast neutrons. They also contain a cadmium lining to exclude thermal neutrons exterior to the detector.

Figure 3-3 is a graph of the shielding factor for each detector obtained from measurements with various thicknesses of polyethylene placed immediately adjacent to the neutron source. There are no unexpected results for the reasons explained previously. However, comparison of the graph results with results in Table 3-7 for similar thicknesses of polyethylene indicate that the shielding effectiveness of polyethylene is greater if the polyethylene is placed close to the neutron source. This can qualitatively be explained as a geometric effect: placing the scattering medium close to the source results in producing a divergent beam of neutrons that reduces the number of neutrons per unit area at more distant locations.

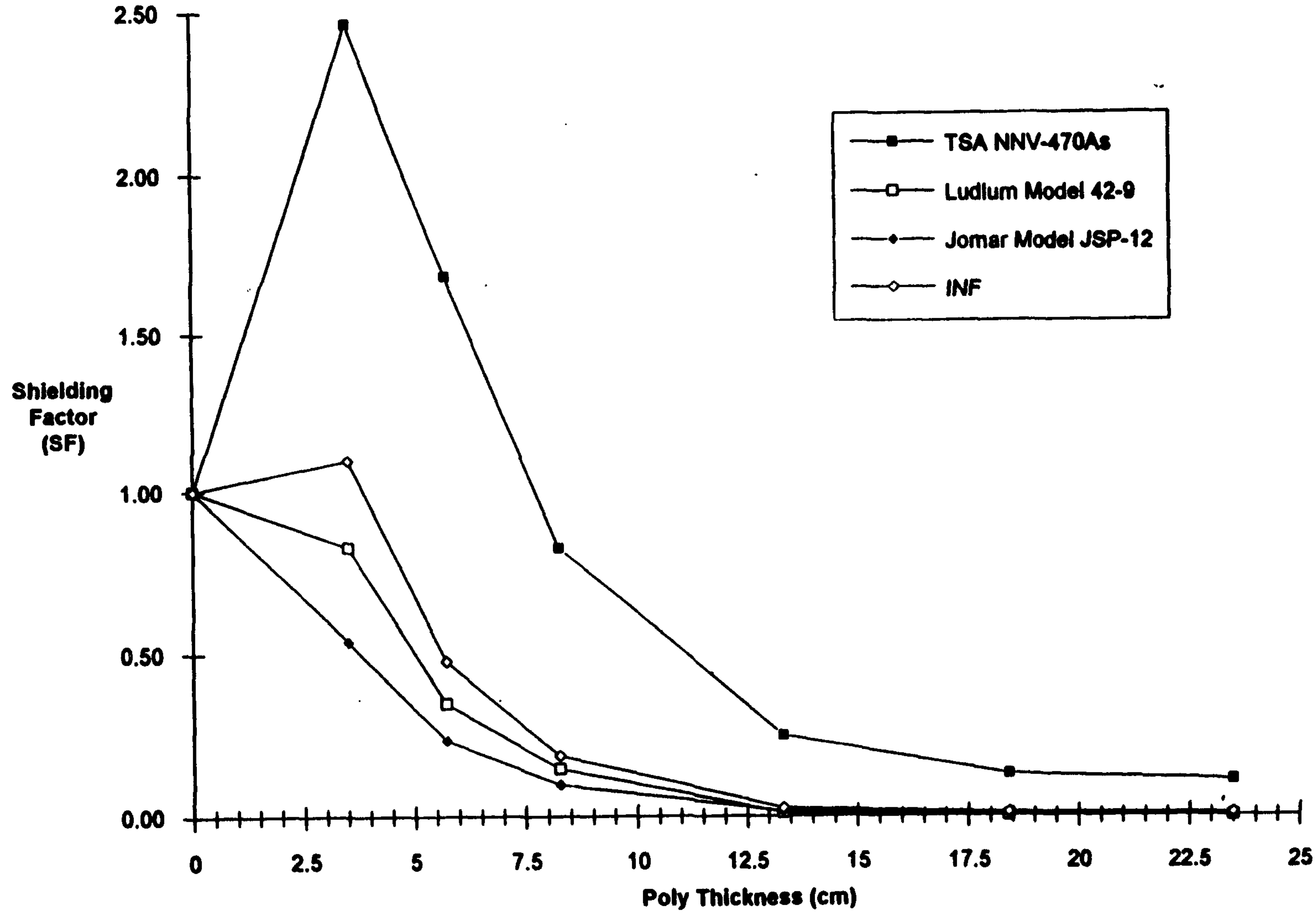


Figure 3-3. Shielding Factors (SF) for poly surrounding strong Am(Li) source at 1m.

3.8 SUMMARY.

The INF, Jomar Model JSP-12, Ludlum Model 42-9, and the TSA NNV-470As neutron detectors were tested at LASF. Measurements at one meter from a "weak" (1750 n/s) Am(Li) neutron source resulted in acceptable data for the INF and Jomar Model JSP-12 neutron detectors but the results for the Ludlum Model 42-9 and TSA NNV-470As neutron detectors were statistically indistinguishable from background. This was also true at the one-half meter distance for the latter two neutron detectors.

The effects of shielding a strong (4.9×10^5 n/s) Am(Li) neutron source with various materials indicated the following:

(1) 1.6 mm of cadmium has no effect on the recorded counts,

(2) 2.5 cm of wood reduces the count rate by less than 10% except for the Jomar Model JSP-12 where the effect is a 20% reduction,

(3) the insertion of polyethylene (up to approximately 5 cm) between the neutron source and TSA NNV-470As detector increases the recorded count rate by a factor of approximately 2.5. The same amount between the source and the other detectors significantly reduces the respective count rates,

(4) there is no difference in shielding effectiveness for equivalent thicknesses of borated and non-borated polyethylene except for the TSA NNV-470As where the borated polyethylene is more effective (an unexpected but explainable result was observed for the Jomar Model JSP-12).

(5) the shielding effectiveness of a specific thickness of polyethylene is greatest if placed adjacent to the neutron source.

The INF and Jomar Model JSP-12 neutron detectors consistently provided results with smaller uncertainties than the Ludlum Model 42-9 and the TSA NNV-470As neutron detectors under comparable exposure conditions.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS.

None of the commercially available neutron radiation detectors tested are capable of satisfying the measurement requirements if the current START Treaty Radiation Detection Equipment procedures are used. The procedure requirement to use a very weak Am (Li) neutron source for the container transmission measurement is the driving factor. Even the use of the INF detector may include an element of risk using the current procedures as explained in Volume 2. The INF detector is not capable of performing the measurement if the criterion derived in this report is used.

Nuclear weapons emit fast neutrons spontaneously and, even though there is high explosive material surrounding the nuclear material, the resultant escaping neutrons still predominately fast neutrons. the physics of efficiently measuring neutrons requires that fast neutrons be slowed down to thermal energies where such nuclear reactions as $^{10}B(n,^{4}He)^{7}Li$, $^{6}Li(n,T)^{4}He$, or $^{3}He(n,p)T$ can be used as the detection mechanism. The last reaction is preferred because of the very high cross section for the interaction (5330 barns). ^{3}He is a gas that allows easy measurement of the ionization due to the reaction, and is non-toxic. Thus, the design of an efficient neutron detector requires a low atomic number (Z) material, such as polyethylene, to surround cylindrical tubes of ^{3}He. The size and arrangement of these components is dependent upon the measurement application. The measurement of high emission rate sources can be accomplished with relatively small and light weight detectors. However, very weak neutron emitting sources require large surface area detectors that are bulky and heavy. Therefore, it is highly unlike that a small, light weight neutron detector can be made that will satisfy the OSIA requirements if the current Treaty RDE Procedures must be used to make the measurement.

Reducing the separation distance between source and detector would significantly improve the detection capability since the count rate varies as the inverse square of the separation distance; i.e., reducing the separation distance from, say, two meters to one meter would increase detector count rates by a factor of four. Also, increasing the counting time would permit the recording of more counts and improve the accuracy. The relationship is linear, thus, doubling the counting time will double the number of counts and improve the uncertainty associated with the measurement by a factor of 1.414 (the square root of two). Finally, for a geven measurement geometry, the count rates increase linearly with the increase of the source strength.

4.2 RECOMMENDATION.

It is recommended that the Treaty RDE Procedure be changed in order to satisfy the OSIA requirements for suitable RDE equipment. An approximately two order of magnitude (factor of 100) improvement in the number of accumulated counts is required to provide high confidence results. Since source-detector to provide high confidence results. Since source-detector separation distance may be limited by container dimensions and counting times may be limited by operational considerations, the most practical change would be the neutron source strength. However, increasing the source strength by a factor of 100, imposes safety concerns which should be relatively easily solved by designing an appropriate storage container for the source when not in use.

Appendix A
OSIA Requirements for New Radiation Detection Equipment (RDE)

On-Site Inspection Agency
Washington, D.C. 20041-0498

FEB 12 1993

MEMORANDUM FOR DEPUTY DIRECTOR, STRATEGIC ARMS CONTROL AND COMPLIANCE, OFFICE OF UNDER SECRETARY OF DEFENSE (ACQUISITION)

SUBJECT: Requirements for New Radiation Detection Equipment (RDE)

The Strategic Arms Reduction Treaty (START) allows for the use of RDE during inspections of weapon storage areas and during reentry vehicle on-site inspection. Currently, Annex 8 of the START Inspection Protocol identifies for the United States the same RDE that was used for the Intermediate-Range Nuclear Forces (INF) Treaty. Since the Russians have stated that they wish to use equipment different than the INF RDE, the On-Site Inspection Agency (OSIA) desires to use RDE that better meets START application.

The new equipment generally needs to be smaller, lighter, less costly, and easier to use than the current INF RDE. OSIA currently owns seven INF RDE sets (original cost $80,000 per set), six of which are distributed between the U.S. Gateways and the Russian POEs. With the possibility of additional POEs being established, OSIA may have to purchase as many as 13 sets to meet operational requirements. This makes the cost per set of key importance and drives the requirement for commercial, off-the-shelf equipment. The new set of RDE should be:

a. able to complete measurements at 4 locations per object from a distance of 2 meters within 30 minutes.

b. a self-contained, one-piece intrusion resistant neutron detector and counter with an easy-to-read digital display of the neutron count.

c. off-the-shelf and commercially available.

d. lightweight with total of all equipment not exceeding 40 pounds excluding the carrying case.

e. able to contain all equipment in one existing 26"L x 20"W x 9"H carrying case.

f. rugged enough to withstand transporting in aircraft cargo holds and land vehicles while inside the carrying case.

g. complete with built-in test and calibration equipment and a tripod mounting capability.

h. simple with minimal support equipment.

i. supported by an internal power source capable of 6 hours continuous operation.

OSIA needs to have identified the systems that meet the above criteria as soon as possible. Use of RDE is a major topic for the next session of the JCIC scheduled for March 1993. The type of equipment used will have an effect on coordinated RDE procedures. It is possible that RDE will be needed during the START baseline period so identifying and procuring new equipment may be on an accelerated schedule.

OSIA is prepared to expeditiously assist in this matter. The point of contact is Major Pandolfi, (703)742-4599.

FOR THE DIRECTOR:

Ronald P. Forest
Colonel, U.S. Army
Chief of Staff

Appendix B
Descriptions of Tested Radiation Detection Equipment

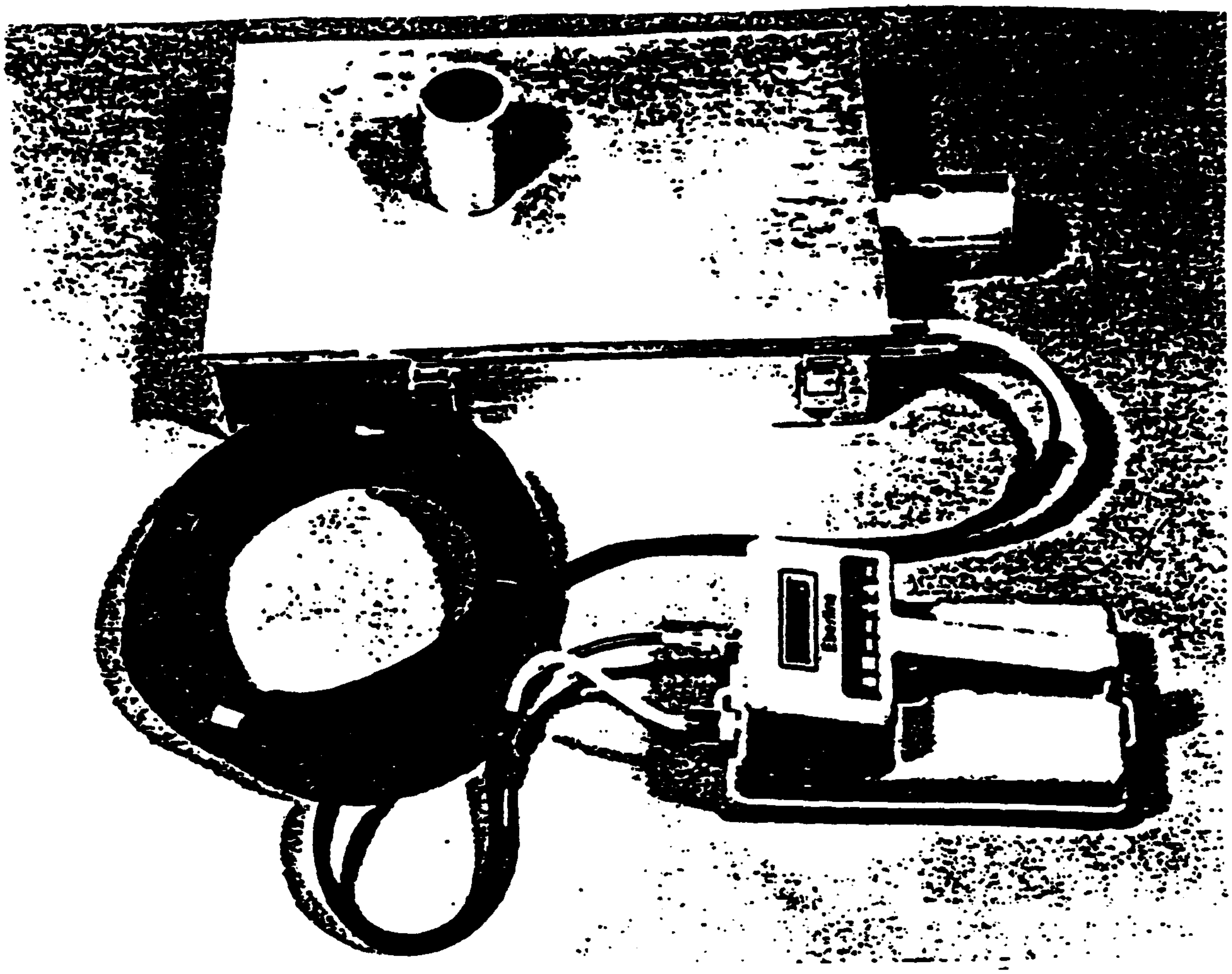


Figure B-1. INF neutron detector (provided by Sandia National laboratory).

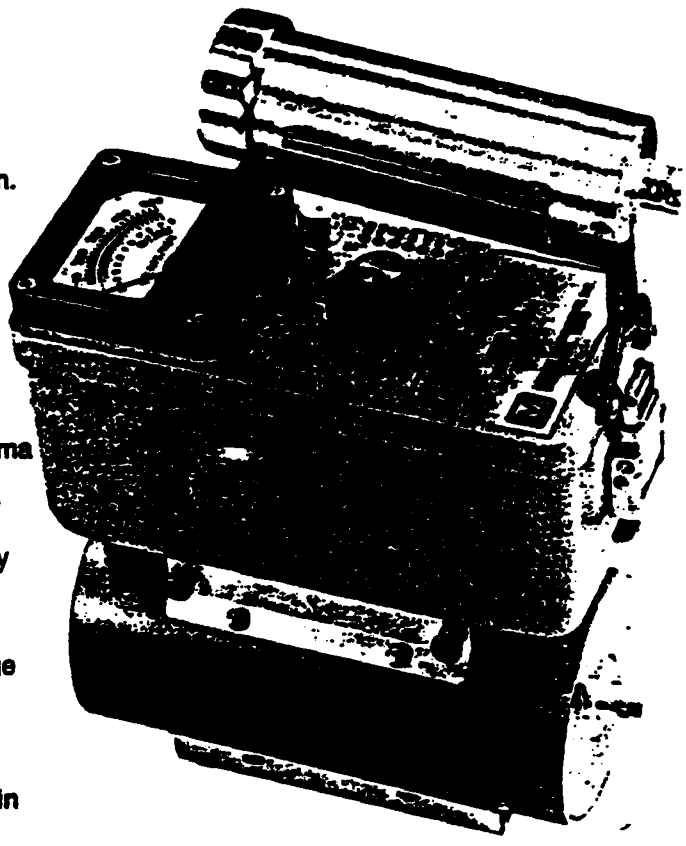
The helium-3 tubes are obtained commercially from several manufacturers. They are nominally 2.5 cm in diameter, 25 cm in active length, and are filled to a pressure of ten atmospheres. Twelve identical tubes, arranged in two rows of six each,a re inserted into holes of diameter 2.6 cm drilled 29.5 cm through a polyethylene block of external dimensions 25.4 x 29.5 x 6.35 cm, covered with a cadmium sheet of thickness 0.08 cm. The tubes arranged in the polyethylene so that the detector is symmetrical front-to-back. The output pulses from the tubes are applied to a preamplifier, which is necessary to drive the detector pulses through the 15 meter cables to the electronic control unit. The detector and the preamplifier are contained in an aluminum box. the electronic control unit is commercially available and is battery powered. It supplies high voltage to the tubes (about 1600 volts), powers the preamplifier, amplifies and counts the pulses in an adjustable time interval, and displays the result. A threshold discriminator is adjusted to eliminate low-level pulses due to gamma rays and electronic noise.

LUDLUM MEASUREMENTS, INC.

P.O. Box 810 / 501 Oak Street
SWEETWATER, TEXAS 79556
Phone: 800/622-0828(USA), 915/235-5494 Fax: 915/235-4672

MODEL 15

FAST and THERMAL NEUTRON and ALPHA BETA-GAMMA SURVEY METER



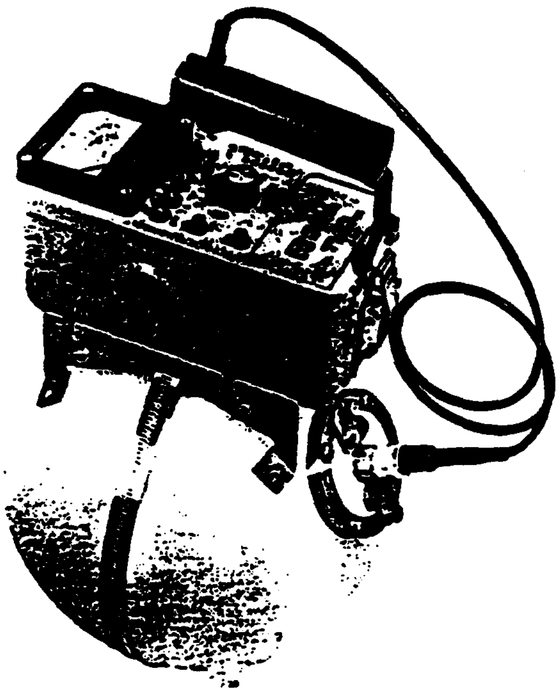
HV: Alpha Beta-Gamma detector fixed at 900 volts. Neutron setting allows HV to be adjusted up to 2500 volts for the neutron detector.
AUDIO: Built in unimorph speaker with an ON/OFF switch.
RESPONSE: Toggle switch for FAST (4 seconds), or SLOW (22 seconds) for 90 % final reading.
RESET: Push button to zero after overrange exposure.
METER: 0-500 cpm, HV readout.
MULTIPLIER RANGES: X1; X10; X100; X1000.
BATTERIES: 2 each, "D" cell with 300 hours typical life.
DETECTORS: Neutron:BF_3 thermal detector with 7.6(3") diameter Cd-lined moderator for fast neutrons. Peak efficiency at about 0-8 MeV. Remove detector from moderator to determine fast neutron response. Gamma cut off greater than 10 R/hr. Neutron efficiency is 66 cpm at 50 mrem/hr; 72 cpm at 10 mrem/hr for AmBe neutrons.
<u>Note:</u> Count response is not linear throughout the energy spectrum due to limitations of the moderator.
G-M: Model 44-7 (See specs in detector section of catalog)
CONSTRUCTION: Cast and drawn aluminum with a beige polyurethane paint finish.
SIZE: 8.6(3.4")W X 26.6(10.5")H X 19(7.5")L.
WEIGHT: 3.4(7.5pounds) with both detectors.

Note: Model 44-7 and Neutron detector are included in the price.

Figure B-2. Ludlum Model 15 neutron detector.

LUDLUM MEASUREMENTS, INC.

P.O. Box 810 / 501 Oak Street
SWEETWATER, TEXAS 79556
Phone: 800/622-0828(USA), 915/235-5494 Fax: 915/235-4672



MODEL 12-4

NEUTRON COUNTER WITH REMOVABLE DETECTOR. NEAR REM RESPONSE

ENVIRONMENT: Splashproof shields for outdoor use.
CALIBRATION CONTROLS: HV to set Gamma cut off; individual range controls to calibrate detector efficiency.
AUDIO: Built-in unimorph speaker with an ON/OFF switch.
RESPONSE: Toggle switch for FAST (4 seconds), or SLOW (22 seconds) for 90 % of final reading.
RESET: Push button to zero for overrange exposure.
METER: 0-10 mrem/hr.
MULTIPLIER RANGES: X1; X10; X100; X1000
BATTERIES: 2 each, "D"cell with 300 hours typical life.
DETECTOR: 1.6 cm by 2.5cm BF_3 detector surrounded by a 7.6(3") diameter by 0.0038(0.0015") thick Cd shield surrounded by a 22.9(9") diameter poly moderator: This assembly provides an approximate inverse RPG curve for neutrons from the thermal through 10 MeV. Efficiency for AmBe neutrons is approximately 30 cpm/mrem/hr. Gamma cut off exceeds 10 R/hr.
CONSTRUCTION: Cast and drawn aluminum with a beige polyurethane paint finish.
SIZE: 22.8(9") W X 43.1(17")H X 26.6(10.5")L
WEIGHT: 9.5(21 pounds)

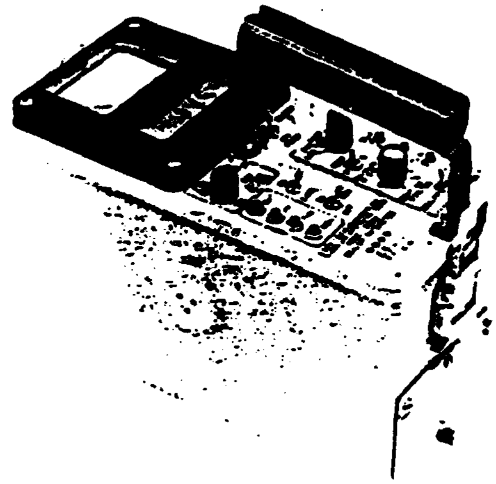
Figure B-3. Ludlum Model 12-4 neutron detection.

LUDLUM MEASUREMENTS, INC.
P.O. Box 810 / 501 Oak Street
SWEETWATER, TEXAS 79556
Phone: 800/622-0828(USA), 915/235-5494 Fax: 915/235-4672

MODEL 2221

PORTABLE SCALER/RATEMETER SINGLE CHANNEL ANALYZER WITH 6-DECADE READOUT 0-999,999

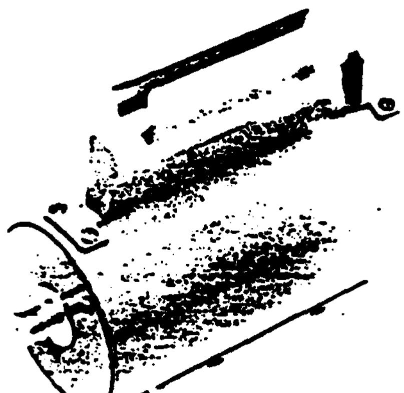
FEATURES: Ruggedized; splashproof; six decade LCD readout with light; combination four decade linear analog and digital ratemeter with log readout; scaler operates independent of ratemeters; adjustable HV threshold, and window positions with readouts on digital display; battery test, and low battery indication; operates scintillation, proportional and G-M detectors; audio provided by unimorph speaker with automatic pitch change in relation to meter reading; electronic timer; single channel analyzer capability; clicks per event audio with divider select of 1, 10, or 100 events per click.
POWER: 4 each, "D" cell batteries.
BATTERY LIFE: Minimum of 100 hours.
INPUT SENSITIVITY: Voltage sensitive, adjustable from 1.3-100 mV.
HIGH VOLTAGE (HV): 200-2500 volts. (Adjusted by a recessed multi-turn screwdriver control.)
TIMER: Preset 0.1, 0.2, 0.5, 1, 2, 5, 10 minute or continuous.
RESPONSE: FAST (4 seconds) for 90 % of full scale.
SLOW (22 seconds) for 90 % of full scale.
LINEARITY: Typically ±2 % of full scale.
RATEMETER: Traditional analog ratemeter and logarithmic readout (500 - 500,000 cpm) with simultaneous digital ratemeter readout.
HEADSET JACK: Located on front panel.
SIZE: 11.4 (4.5")W X 19 (7.5")H X 24.1 (9.5")L.
WEIGHT: 2.27 (5 pounds), including batteries.



Optional Headset Available

MODEL 42-9

FAST AND THERMAL NEUTRON DETECTOR



DETECTOR AND MODERATOR: BF_3 detector with 7.6 (3") diameter X 17.8 (7")L polyethylene, Cd lined moderator for thermal neutrons.
EFFICIENCY: Approximately 60 cpm/mrem/hr for AmBe Neutrons.
ENERGY RESPONSE: Energy dependent. This instrument does not follow the inverse RPG curve.
COMPATIBLE INSTRUMENTS: LMI MODEL 12 and all LMI Scalers. (HV adjustment 0 - 2500 volts)
GAMMA REJECTION: 10 R/hr.
SIZE: 7.6 (3")W X 15.2 (6")H X 17.8 (7")L
WEIGHT: 1.8 (4 pounds)

Figure B-4. Ludlum Model 42-9 neutron detection and Ludlum Model 2221 scaler.

CANBERRA NUCLEAR

Model JSP-12
Shielded Neutron Assay Probe

Features

- Portable neutron probe for JHH-41 Hand-Held Verification Instrument and JSR-11/12 Neutron Coincidence Analyzer
- Light weight - 9 kg (20 lbs)
- Fast Amptek electronics
- Two 8-inch ^3He proportional counters
- Operates in coincidence or scaler mode

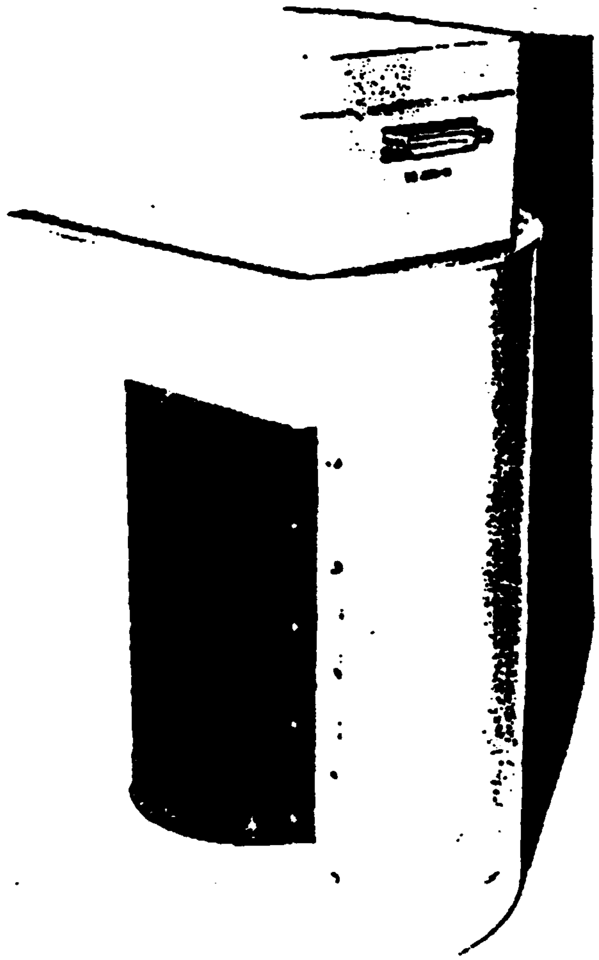
Description

The JSP-12 Shielded Neutron Assay Probe (SNAP-II), which is based on Los Alamos National Laboratory design, is intended to be used to verify plutonium oxide, uranium oxide, uranium hexafluoride cylinder contents, uranium tetrafluoride "green" salt and metallic plutonium buttons. The portable assay probe can be operated without shielding or inside a shield included with the unit.

The SNAP-II[1] has the following improvements over the SNAP:

- Improved efficiency
- A flatter neutron energy response
- A flatter vertical position response
- Geometry changes to allow closer coupling with the sample
- Amptek amplifier/discriminator circuitry

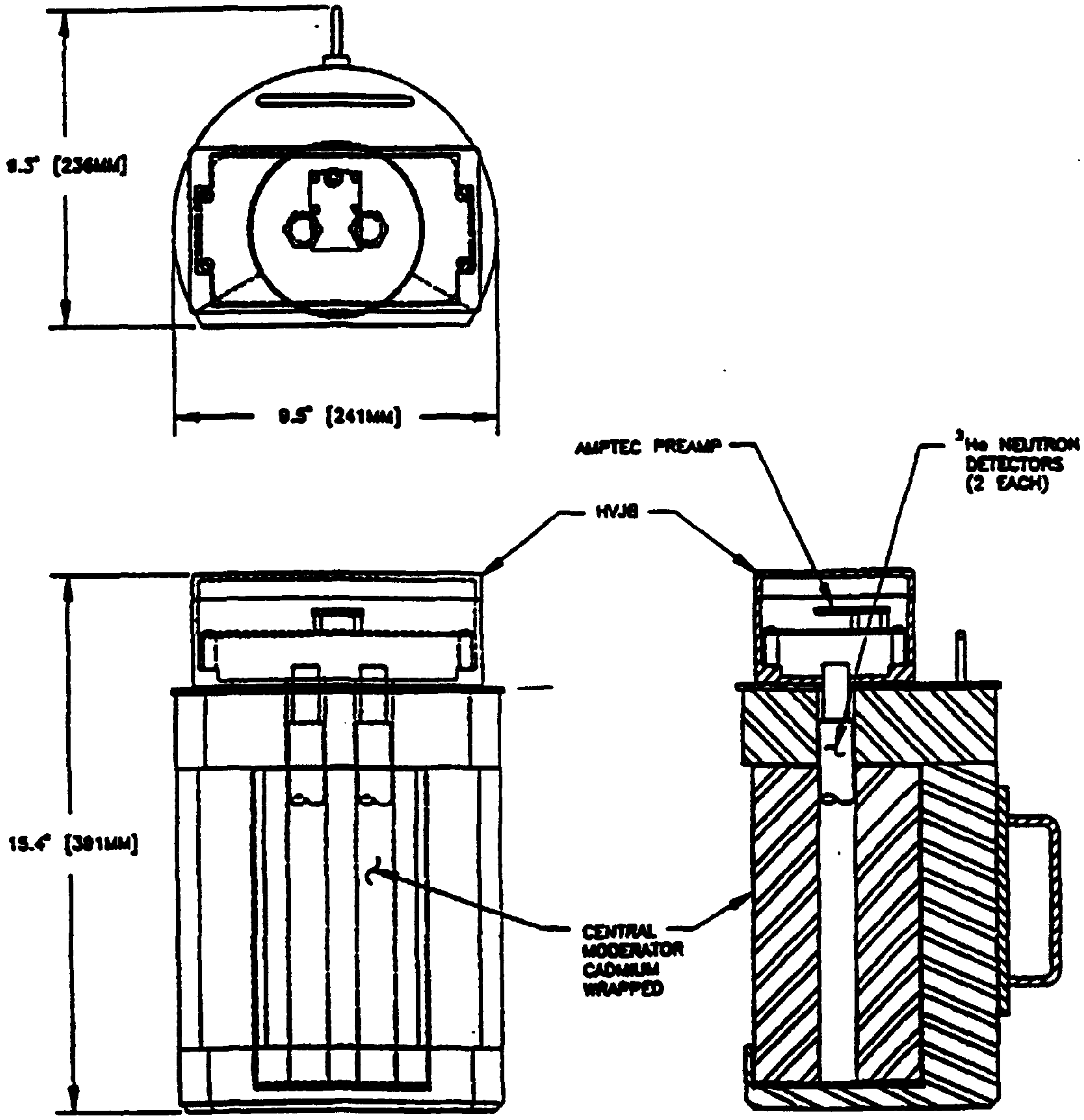
The JSP-12 is designed to operate with the battery-powered JHH-41 Hand-Held Verification Instrument to scale total counts. When operated with the JSR-11/12 Neutron Coincidence Analyzer, coincidence events from spontaneous fission are counted. The JSP-12 contains two 8-inch long ^3He tubes which are placed inside a 5-inch diameter, 9-inch long high-density polyethylene moderator which is surrounded by a 0.016-inch thick cadmium sleeve. The moderator is surrounded by a removable outer polyethylene shield that is 9.75 inches in diameter. Use of the shield provides a directional response. The two ^3He tubes are wired together and connected to an JAB-01 Preamplifier/Discriminator circuit board mounted in a sealed junction box located on the top of the probe. The junction box also houses the high voltage power supply board.



REFERENCE

1. Memo, Dr. Howard Menlove, Los Alamos National Laboratory, Los Alamos, NM 87545, December, 1975.

Figure B-5. Jomar Model JSP-12 neutron detector and Model JHH-41 scaler.



Model JSP-12 Shielded Neutron Assay Probe

Figure B-5. Jomar Model JSP-12 neutron detector and Model JHH-41 scaler (Continued).

CANBERRA NUCLEAR

ND

Models JHH-31 and JHH-41 Hand-Held Verification Instruments

Features

- Small size - 9 X 13 X 20 cm (H X W X D)
- Light weight - 1.8 kg (4 lbs)
- Microcomputer-controlled
- LED gain stabilization
- Long battery life (greater than 16 hours per charge)
- Lower Level Discriminator (LLD) and three Single Channel Analyzers (SCAs)
- 4-digit LCD display
- Simple SCA adjustment using on-board display
- Crystal-controlled count interval
- Stabilized detector eliminates the need for recalibration with a reference spectrum before each verification

Description

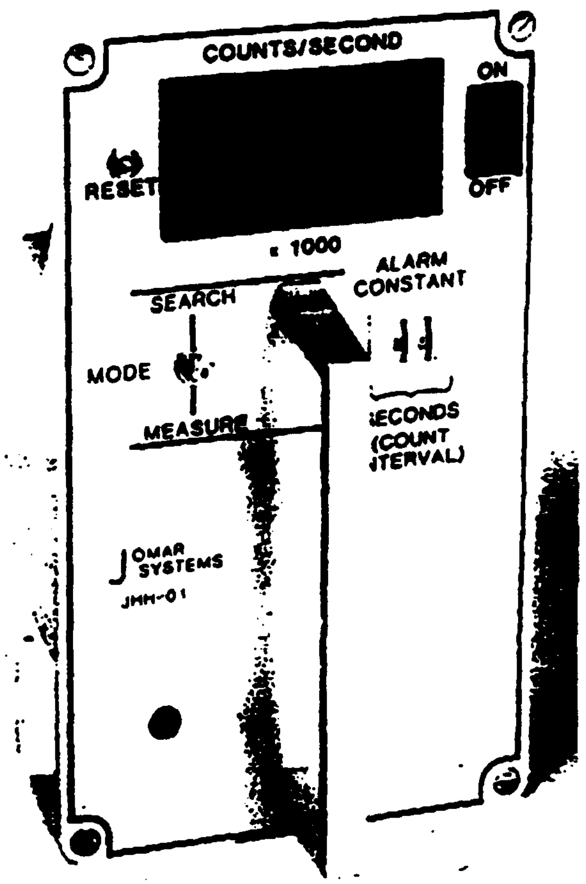
The Hand-held Verification Instruments are designed to be used to search pedestrians and vehicles for Special Nuclear Material (SNM) as part of a physical security protection plan. The versatility built into these instruments allows them to be used for tasks including simple searches, verification of material type or enrichment, verifying the absence of SNM on pedestrians with medical isotope uptake, measuring SNM process holdup, verifying the SNM mass category of samples and verifying the presence of isotopes other than SNM.

The Hand-held Verification Instruments can be operated in several modes. In the SEARCH mode, all counts above a lower-level discriminator (LLD) are used to determine a count rate. The 0.05 second long counts preserve sensitivity while providing the fast signal response needed for hand monitoring. The alarm threshold is calculated by adding the measured background to the number set in the front panel thumbwheel switch. The MEASURE mode makes use of the three single channel analyzers (SCAs) in addition to the LLD. In this mode, an internal switch selects one of three separate types of operation. These operations include:

- Counts per second above the LLD. This operation is similar to the SEARCH mode except that the count interval is selected with the front panel thrumbwheel switch. Longer count intervals can be used to increase sensitivity.
- Background subtracted counts per second in the center SCA with the other two SCAs defining the background regions. This operation can be used to verify the presence of specific isotopes and is particularly useful when a fluctuating background is suspected.
- An enrichment measurement using the ratio of the counts in two of the SCAs.

Material found in the SEARCH mode can be scrutinized in the MEASURE mode to determine the SNM quantity, enrichment or to verify the material type.

The Hand-held Verification Instruments are available with an internal NaI detector or a version that accepts external detectors. The JHH-31 contains an internal 1 X 2 inch thick NaI detector that is gain stabilized without the use of any radioactive material. The detector assembly contains a light pipe with a green light emitting diode (LED) that flashes light into the scintillator. The thermally-stabilized LED current produces 200 light pulses per second which are counted in the stabilization SCAs and used for amplifier gain stabilization.[1] The SCAs are positioned well above the gamma-ray pulse heights. Measured gain stability is 1.5% over a temperature range from -2 to 33° C.

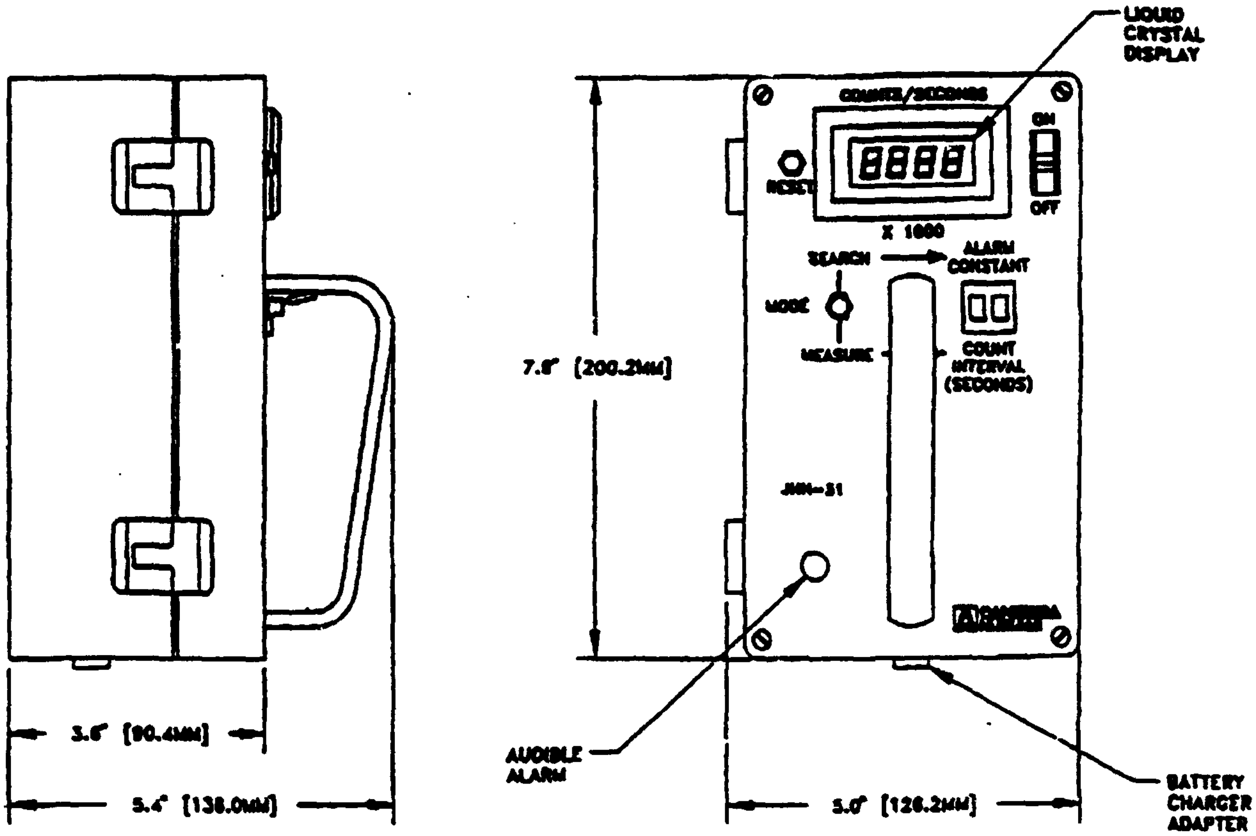


The JHH-41 is designed to operate with remote detector probes including the JSP-12 Shielded Neutron Assay Probe and the JSC-45, JSC-46 and JSC-47 NaI Detector Shield/Collimators. The JSP-12 contains two ^{3}He proportional counters wired to an JAB-01 Preamplifier/Discriminator circuit board. The ^{3}He tubes are surrounded by high-density polyethylene. The JSC-45, JSC-46 and JSC-47 are lead shield/collimators which house various size NaI detectors, each with LED stabilization. The JSC-45 contains a 1 X 0.5 inch thick NaI detector; the JSC-46, a 1 X 2 inch thick NaI detector; and the JSC-47, a 2 X 0.5 inch NaI detector. The JHH-41 is able to recognize which detector is connected to it and to modify its operation accordingly. Since the high voltage power supply boards are located in the remote probes, adjustment of the high voltage is not required when detectors are changed.

Reference

"Stabilized, Hand-Held, Gamma-Ray Verification Instrument for Special Nuclear Material," Paul E. Fehlau and Gary Wiig, Los Alamos National Laboratory Report, LA-UR-88-3673, November 1988

Figure B-5. Jomar Model JSP-12 neutron detector and Model JHH-41 scaler (Continued).



Models JHH-31 and JHH-41 Hand-Held Verification Instruments

Figure B-5. Jomar Model JSP-12 neutron detector and Model JHH-41 scaler (Continued).

NNV-470

DESCRIPTION The NNV-470 is a gamma-neutron sensitive version of the PRM-470A. The basic electronic package is identical, with the exception of the detector assembly. The gamma sensitive NAI or plastic scintillator is replaced with a thin LiI(Eu) detector which is shielded by a neutron thermalizing plastic to achieve neutron sensitivity. A "calibrate" switch accesses a low-level discriminator to allow gamma counting to verify instrument operation.

APPLICATIONS The NNV-470 *(Non Nuclear Verification)* unit was designed specifically to verify neutron flux in high gamma backgrounds, as would be the case in SNM environments.

The design of the NNV-470 allows a gamma check source to be used to verify proper instrument operation on power-up and then automatically switch to neutron measuring mode without operator input.

TYPICAL OPERATION Very similar to the PRM-470A. Details on actual operation may be obtained from TSA Systems.

SPECIFICATIONS All NNV-470 specifications are identical to the PRM-470 in terms of size, weight, battery life, and back-lighted display. Counting timers and sequencing of gamma and neutron count rates are factory-changeable to meet operator requirements. The NNV-470, in addition, features a fold-over handle for ease of transporting.

TSA systems ltd.

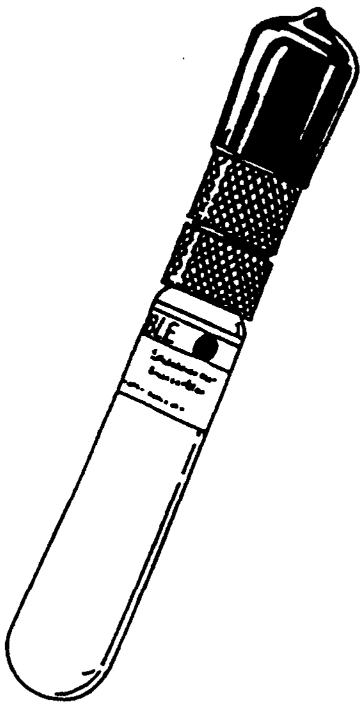
P.O. Box 797
1820 Delaware Place
Longmont, CO 80502
Phone: (303) 651-6147
Fax: (303) 651-6823

Figure B-6. TSA NNV-470As neutron detector.

BTI BUBBLE Technology Industries

NEUTRON DETECTORS

BD 100R O/F



FEATURES:

- Ultra High Sensitivity (< 0.5 uSv)
- Real Time Immediate Response
- Tissue Equivalent Response
- Completely Passive Operation
- Flat Energy Response (200 keV to 14 MeV)
- Insensitive to Gamma Rays
- Inherently Isotropic Response
- Compact, Lightweight
- High Strength Plastic Construction

The Bubble Technology BD 100R O/F is a reusable, passive integrating dosimeter that allows instant, visible detection of neutron radiation. The BD 100R O/F consists of an elastic polymer throughout which droplets of superheated liquid have been dispersed. When these droplets are struck by neutrons they form small gas bubbles which remain fixed in the polymer to provide a visual record of the dose. The dose is directly proportional to the number of bubbles. The detectors can be reset using an integral recompression device and can be reused for up to three months when reset daily.

The BD 100R O/F offers a dose range two orders of magnitude more sensitive than any other commercial neutron dosimeter (< 1 uSv) and has a flat energy response from about 200 keV to 14 MeV. Unlike old style film dosimeters, the BD100R O/F gives an intermediate and permanent visual response. No chemical or mechanical processing subject to operator error is involved.

Unlike many active (electronic) dosimeters the BD 100R O/F is completely insensitive to gamma radiation. In addition, the bubble detectors are so compact they can be located in areas with limited space for access or in close proximity to the neutron source increasing detection efficiency. Unlike any other neutron dosimeter, the BD 100R O/F can be used under water with no effect on performance.

Unlike damage track detectors such as CR-39, the BTI bubble detector has a completely isotropic angular response so that neutron doses can be accurately recorded regardless of the direction of the neutrons relative to the detector.

The BD 100R O/F bubble detector is the method of choice for personnel monitoring of neutrons, area monitoring and shielding and leakage checks. The BD 100R O/F and custom variants have been used in applications as diverse as electronic radiation hardening studies and meaurement of neutron fluences in outer space.

Figure B-7. Bubble dosimeter

SPECIFICATIONS: BD 100R O/F

Neutron Energy Response:	< 200 keV to > 15 MeV (plus or minus 10% for most neutron fields)
Dose Range:	< 1 uSv to > 0.01 Sv (< 0.1 mRem to >1 Rem)
Sensitivity:	Typically 0.33 to 33 bubbles / mrem *
Gamma Sensitivity:	Insensitive
Angular Response:	Isotropic (Independent of Angle)
Reusable:	Yes
Useful Life:	Three months if recycled daily
Shelf Life:	To one year at ambient T
Operating Range:	
Temperature	10 - 35 °C
Humidity	To 100%
Size:	18 mm dia. x 118 mm length (0.71" x 4.6")
Weight:	38 gram (1.34 oz)

* Typical sensitivities : 0.33, 2.2 and 27.0 bubbles / mrem. Intermediate sensitivities available on request.

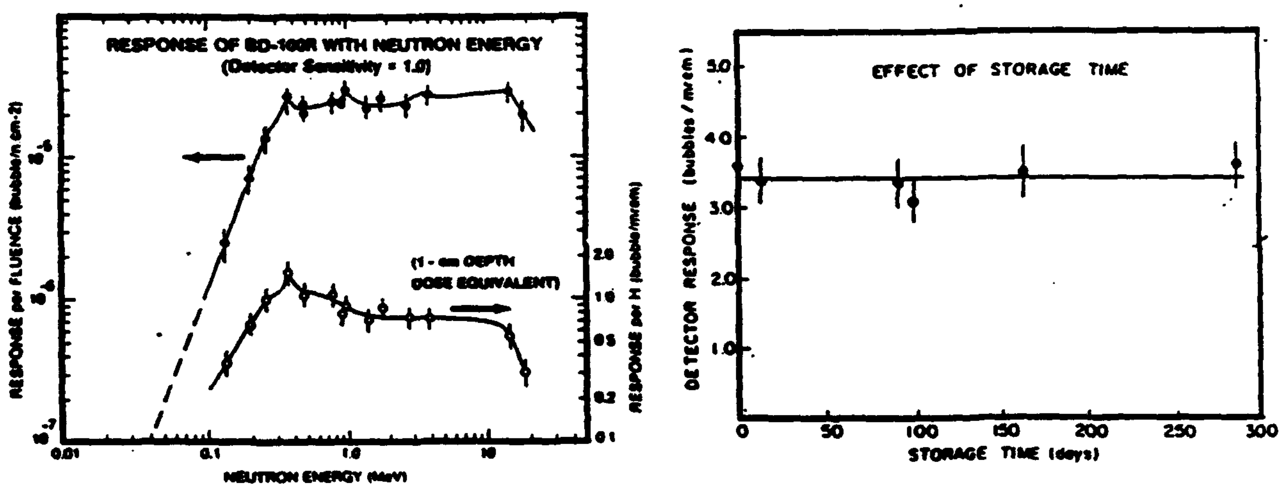


Figure B-7. Bubble dosimeter (Continued).

Appendix C
RDE Data from Tests at Andrews AFB

Appendix C: RDE Data from Tests at Andrews AFB

The following Appendix contains a listing of data collected during the two days of RDE testing at Andrews AFB. The data are presented in the following order:

- Background measurement data
- Gamma-ray sensitivity data
- Radial measurement data for unmoderated source
- Radial measurement data for moderated source
- Position sensitivity data for unmoderated source
- Position sensitivity data for moderated source
- INF measurement data for moderated source

The INF detector data is listed separately (from the other detector data) since it was not included in all of the tests conducted. Due to the set-up (i.e., on a tripod) of that detector, it was not positioned at different positions around an arc as was the procedure for the other detectors during the position sensitivity measurements. Rather, the INF detector was placed at various distances from the source and measurements recorded for each position. Since position bias did not occur for the other detectors, it is reasonable to assume that this deviation from the test plan for the INF detector did not affect the resulting data analysis and conclusions.

Other points to note when considering the data presented in the tables which follow are:

- Measurements and calculations are presented with three significant figures; and

- Bubble dosimeter measurement data are presented in terms of "average counts per 720 seconds." The averages shown are based on three readings of the dosimeters for three separate angular positions (in the dosimeter reader). This accounts for fractions of bubbles appearing in the data tables.

Table C-1. Background measurement data.

2/17/93

Detector: NNV-470As

time		counts/20 sec		average counts/20 sec	cps	average cps
1030	0	0	0	0.00	0.00	0.0229
	0	0	0	0.00	0.00	
	0	1	1	0.667	0.0333	
	0	0	0	0.00	0.00	
	0	0	1	0.333	0.0167	
	1	0	1	0.667	0.0333	
	0	2	0	0.667	0.0333	
	1	3	0	1.33	0.0667	

Detector: Ludium Model 15

time	scale setting	1000s of counts/minute	cps	average cps
1032	1	0.030	0.500	0.417
1041	1	0.030	0.500	
1045	1	0.030	0.500	
1046	1	0.020	0.333	
1047	1	0.020	0.333	
1048	1	0.020	0.333	
1050	1	0.020	0.333	
1052	1	0.030	0.500	

2/18/93

Detector: NNV-470As

time		counts/20 sec		average counts/20 sec	cps	average cps
852	2	1	0	1.00	0.0500	0.0438
	2	0	3	1.67	0.0833	
	1	1	1	1.00	0.0500	
	0	0	2	0.667	0.0333	
	0	1	1	0.667	0.0333	
	0	1	1	0.667	0.0333	
	0	0	4	1.33	0.0667	
	0	0	0	0.00	0.00	

Detector: Ludium Model 15

time	scale setting	1000s of counts/minute	cps	average cps
850	1	0.01	0.167	0.167
857	1	0.01	0.167	
900	1	0.01	0.167	

Detector: INF

time	counts per 100 seconds	cps	average cps
910	105	1.05	0.963
	96	0.960	
	87	0.870	
	84	0.840	
	105	1.05	
	101	1.01	

Table C-2. Gamma-ray sensitivity measurement data.

2/18/93
Time: 1604

detector	position (1)	scale setting	counts	cps
Ludlum Model 15	C	1	0.0620	1.03
Ludlum Model 12-4	F	1	0.00	0.00
NNV-470As	D	N/A	2.00	0.100
Jomar Model JSP-12	E	1000	0.0160	0.160
Ludlum Model 42-9	A	1	0.00	0.00

(1) Refer to Figure 2.11

Table C-3. Radial measurement data for unmoderated source.

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Detector: Ludium Model 15

Positive radial axis

time	r (cm)	scale setting	1000s of counts per minute	cps	r (cm)	average cps
1309	32.5	100	0.030	50.0	32.5	50.0
1315	32.5	100	0.030	50.0	50	28.3
1317	32.5	100	0.030	50.0	75	11.7
1320	50	100	0.020	33.3	100	8.11
1322	50	10	0.160	26.7	125	5.00
1324	50	10	0.150	25.0	150	4.17
1326	75	10	0.070	11.7	200	2.46
1328	75	10	0.070	11.7		
1330	75	10	0.070	11.7		
1332	100	10	0.050	8.33		
1334	100	10	0.050	8.33		
1336	100	10	0.046	7.67		
1337	125	10	0.033	5.50		
1339	125	10	0.031	5.17		
1340	125	10	0.026	4.33		
1342	150	1	0.240	4.00		
1344	150	1	0.290	4.83		
1345	150	1	0.220	3.67		
1346	200	1	0.200	3.33		
1347	200	1	0.140	2.33		
1349	200	1	0.140	2.33		
1351	200	1	0.110	1.83		

Negative radial axis

time	r (cm)	scale setting	1000s of counts per minute	cps	r (cm)	average cps
1353	200	1	0.160	2.67	32.5	72.2
1355	200	1	0.140	2.33	50	29.7
1356	200	1	0.140	2.33	75	13.5
1357	150	1	0.210	3.50	100	7.83
1359	150	10	0.030	5.00	125	5.94
1400	150	10	0.030	5.00	150	4.50
1401	125	10	0.035	5.83	200	2.44
1402	125	10	0.037	6.17		
1403	125	10	0.035	5.83		
1405	100	10	0.038	6.33		
1408	100	10	0.053	8.83		
1409	100	10	0.050	8.33		
1411	75	10	0.082	13.7		
1412	75	10	0.080	13.3		
1413	75	10	0.081	13.5		
1414	50	10	0.175	29.2		
1415	50	10	0.181	30.2		
1416	50	10	0.178	29.7		
1419	32.5	100	0.045	75.0		
1420	32.5	100	0.043	71.7		
1421	32.5	100	0.042	70.0		

Table C-3. (continued) Radial measurement data for unmoderated source.

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Detector: Ludium Model 15

Positive radial axis

time	r (cm)	scale setting	1000s of counts per minute	cps	r (cm)	average cps
928	32.5	100	0.040	66.7	32.5	65.6
930	32.5	100	0.039	65.0	50	24.4
932	32.5	100	0.039	65.0	75	12.2
934	50	10	0.150	25.0	100	8.33
936	50	10	0.150	25.0	125	5.00
938	50	10	0.140	23.3	150	4.72
939	75	10	0.070	11.7	200	2.50
940	75	10	0.080	13.3		
941	75	10	0.070	11.7		
940	100	10	0.050	8.33		
941	100	10	0.050	8.33		
942	100	10	0.050	8.33		
943	125	10	0.030	5.00		
944	125	10	0.030	5.00		
945	125	10	0.030	5.00		
946	150	10	0.029	4.83		
947	150	10	0.029	4.83		
948	150	10	0.027	4.50		
950	200	1	0.160	2.67		
951	200	1	0.140	2.33		
952	200	1	0.150	2.50		

Detector: INF

Negative radial axis

time	r (cm)	counts per 100 seconds	cps	r (cm)	average cps
930	100	6.64E+04	664	75	1000
931	100	6.67E+04	667	100	663
933	100	6.59E+04	659	150	352
935	75	9.98E+04	998	200	227
940	75	1.01E+05	1010		
941	75	1.01E+05	1010		
943	150	3.51E+04	351		
945	150	3.54E+04	354		
948	150	3.50E+04	350		
951	200	2.27E+04	227		
953	200	2.26E+04	226		
955	200	2.28E+04	228		

Table C-4. Radial measurement data for moderated source.

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Detector: Ludlum Model 15

Negative radial axis

time	r (cm)	scale setting	1000s of counts per minute	cps	r (cm)	average cps
1433	50	10	0.190	31.7	50	31.7
1435	50	10	0.190	31.7	75	16.1
1437	50	10	0.190	31.7	100	9.56
1439	75	10	0.095	15.8	125	6.56
1440	75	10	0.097	16.2	150	4.78
1441	75	10	0.097	16.2		
1443	100	10	0.058	9.67		
1444	100	10	0.055	9.17		
1445	100	10	0.059	9.83		
1446	125	10	0.039	6.50		
1446	125	10	0.039	6.50		
1447	125	10	0.040	6.67		
1448	150	10	0.027	4.50		
1448	150	10	0.030	5.00		
1449	150	10	0.029	4.83		

Positive radial axis

time	r (cm)	scale setting	1000s of counts per minute	cps	r (cm)	average cps
1456	200	1	0.180	3.00	77	15.3
1458	200	1	0.160	2.67	100	8.89
1459	200	1	0.170	2.83	125	6.50
1501	150	10	0.032	5.33	150	4.89
1502	150	10	0.028	4.67	200	2.83
1503	150	10	0.028	4.67		
1504	125	10	0.040	6.67		
1505	125	10	0.037	6.17		
1507	125	10	0.040	6.67		
1509	100	10	0.060	10.0		
1511	100	10	0.050	8.33		
1513	100	10	0.050	8.33		
1514	77	10	0.090	15.0		
1515	77	10	0.090	15.0		
1517	77	10	0.095	15.8		

Table C-5. Position sensitivity measurement data for unmoderated source.

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Detector: Ludium Model 15

time	position (1)	scale setting	1000s of counts per minute	cps	position (1)	average cps
1055	A	10	0.035	5.83	A	5.83
1057	A	10	0.040	6.67	B	6.61
1059	A	10	0.030	5.00	C	8.89
1032	B	10	0.039	6.50	D	6.67
1034	B	10	0.040	6.67	E	6.67
1036	B	10	0.040	6.67	F	6.06
1006	C	10	0.060	10.0	All	6.79
1008	C	10	0.050	8.33		
1010	C	10	0.050	8.33		
1015	D	10	0.040	6.67		
1017	D	10	0.040	6.67		
1019	D	10	0.040	6.67		
1022	E	10	0.040	6.67		
1024	E	10	0.040	6.67		
1026	E	10	0.040	6.67		
1049	F	10	0.030	5.00		
1051	F	10	0.040	6.67		
1053	F	10	0.039	6.50		

Detector: Ludium Model 12-4

time	position (1)	scale setting	mrem per hour	cps (2)	position (1)	average cps
1054	A	1	1.60	12.4	A	12.7
1056	A	1	1.70	13.2	B	12.2
1058	A	1	1.60	12.4	C	13.0
1101	B	1	1.60	12.4	D	13.2
1104	B	1	1.60	12.4	E	13.7
1109	B	1	1.50	11.7	F	13.5
1026	C	1	1.60	12.4	All	13.0
1028	C	1	1.80	14.0		
1030	C	1	1.60	12.4		
1033	D	1	1.80	14.0		
1039	D	1	1.70	13.2		
1041	D	1	1.60	12.4		
1043	D	1	1.80	14.0		
1011	E	1	1.80	14.0		
1012	E	1	1.70	13.2		
1014	E	1	1.60	12.4		
1019	F	1	1.60	12.4		
1020	F	1	2.00	15.6		
1022	F	1	1.60	12.4		

(1) See Figure 2.11.
(2) See Section 2.6.1 for transformation of mrem/hour to cps.

Table C-5. (continued) Position sensitivity measurement data for unmoderated source.

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Detector: NNV-470As

time	position (1)	counts per 20 seconds	cps	position (1)	average cps
1025	A	92.0	4.60	A	4.48
1027	A	89.0	4.45	B	4.65
1029	A	88.0	4.40	C	4.80
1016	B	93.0	4.65	D	4.48
1017	B	103	5.15	E	4.42
1020	B	83.0	4.15	F	4.48
1032	C	109	5.45	All	4.55
1035	C	96.0	4.80		
1040	C	83.0	4.15		
1006	D	96.0	4.80		
1009	D	81.0	4.05		
1010	D	92.0	4.60		
1046	E	87.0	4.35		
1050	E	91.0	4.55		
1053	E	87.0	4.35		
1100	F	100	5.00		
1103	F	95.0	4.75		
1105	F	74.0	3.70		

Detector: Bubble Dosimeter

time	position (1)	average bubbles per 720 seconds (2)	cps	total counts	position (1)	average cps
1000	B	13.0	0.0181	150	B	0.0208
1000	B	8.00	0.0111		E	0.0173
1000	B	14.3	0.0199		All	0.0190
1000	B	13.0	0.0181			
1000	B	13.7	0.0190			
1000	B	13.7	0.0190			
1000	B	13.0	0.0181			
1000	B	2[illegible]	0.0292			
1000	B	15.3	0.0213			
1000	B	24.6	0.0342			
1025	E	13.3	0.0185	125		
1025	E	15.3	0.0213			
1025	E	16.0	0.0222			
1025	E	4.70	0.00653			
1025	E	12.7	0.0176			
1025	E	14.0	0.0194			
1025	E	18.7	0.0260			
1025	E	9.00	0.0125			
1025	E	11.0	0.0153			
1025	E	10.0	0.0139			

(1) See Figure 2.11.
(2) See introductory text in this Appendix for an explanation of fractions of bubbles in the data tables.

Table C-5. (continued) Position sensitivity measurement data for unmoderated source.

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Detector: Ludlum Model 15

time	position (1)	scale setting	1000s of counts per minute	cps	position (1)	average cps
1451	B	10	0.0490	8.17	B	8.28
1452	B	10	0.0500	8.33	C	8.17
1454	B	10	0.0500	8.33	F	7.83
1502	C	10	0.0500	8.33	All	8.09
1504	C	10	0.0490	8.17		
1506	C	10	0.0480	8.00		
1510	F	10	0.0490	8.17		
1512	F	10	0.0470	7.83		
1514	F	10	0.0450	7.50		

Detector: Jomar Model JSP-12

time	position (1)	1000s of counts per 100 seconds	cps	position (1)	average cps
1503	D	32.2	322	D	323
1505	D	32.0	320	E	313
1507	D	32.8	328	F	329
1456	E	31.2	312	All	322
1458	E	31.6	316		
1500	E	31.3	313		
1511	F	32.7	327		
1514	F	33.1	331		
1517	F	32.9	329		

Detector: NNV-470As

time	position (1)	counts per 20 seconds	cps	position (1)	average cps
1502	A	75.0	3.75	A	4.18
1505	A	76.0	3.80	C	4.98
1507	A	100	5.00	D	4.90
1455	C	109	5.45	All	4.69
1457	C	99.0	4.95		
1500	C	91.0	4.55		
1510	D	101	5.05		
1512	D	103	5.15		
1515	D	90.0	4.50		

Detector: Ludlum 42-9

time	position (1)	counts per 60 seconds	cps	position (1)	average cps
1510	A	131	2.18	A	2.06
1511	A	109	1.82	D	2.38
1512	A	130	2.17	F	2.18
1456	D	155	2.58	All	2.21
1457	D	138	2.30		
1458	D	136	2.27		
1502	F	140	2.33		
1503	F	133	2.22		
1504	F	120	2.00		

(1) See Figure 2.11.

Table C-6. Position sensitivity measurement data for moderated source.

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Detector: Ludium Model 15

time	position (1)	scale setting	1000s of counts per minute	cps	position (1)	average cps
1603	A	10	0.051	8.50	A	8.78
1605	A	10	0.052	8.67	B	8.78
1607	A	10	0.055	9.17	C	9.28
1526	B	10	0.052	8.67	D	8.33
1530	B	10	0.054	9.00	E	9.72
1532	B	10	0.052	8.67	F	9.39
1554	C	10	0.052	8.67	All	9.05
1556	C	10	0.057	9.50		
1557	C	10	0.058	9.67		
1610	D	10	0.050	8.33		
1611	D	10	0.050	8.33		
1614	D	10	0.050	8.33		
1537	E	10	0.062	10.3		
1538	E	10	0.052	8.67		
1539	E	10	0.061	10.2		
1546	F	10	0.055	9.17		
1547	F	10	0.057	9.50		
1548	F	10	0.057	9.50		

Detector: Ludium Model 12-4

time	position (1)	scale setting	mrem per hour	cps (2)	position (1)	average cps
1555	A	1	1.00	11.9	A	11.5
1557	A	1	0.90	10.8	B	13.1
1600	A	1	1.00	11.9	C	15.1
1526	B	1	1.10	13.1	D	11.9
1530	B	1	1.20	14.3	E	13.5
1532	B	1	1.00	11.9	F	13.7
1538	C	1	1.80	21.5	All	13.2
1542	C	1	0.80	9.56		
1545	C	1	1.20	14.3		
1546	D	1	1.00	11.9		
1547	D	1	1.00	11.9		
1548	D	1	1.00	11.9		
1603	E	1	1.00	11.9		
1605	E	1	1.20	14.3		
1606	E	1	1.20	14.3		
1527	F	1	1.00	11.9		
1531	F	1	1.20	14.3		
1532	F	1	1.25	14.9		

(1) See Figure 2.11.
(2) See Section 2.6.1 for transformation of mrem/hour to cps.

Table C-6. (continued) Position sensitivity measurement data for moderated source.

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Detector: NNV-470As

time	position (1)	counts per 20 seconds	cps	position (1)	average cps
1535	A	370	18.5	A	17.5
1540	A	336	16.8	B	18.4
1544	A	342	17.1	C	18.9
1350	B	386	19.3	D	19.0
1353	B	348	17.4	E	18.6
1354	B	367	18.4	F	19.0
1602	C	356	17.8	All	18.6
1604	C	394	19.7		
1606	C	386	19.3		
1528	D	371	18.6		
1530	D	379	19.0		
1532	D	387	19.4		
1556	E	359	18.0		
1558	E	380	19.0		
1600	E	377	18.9		
1610	F	389	19.5		
1612	F	364	18.2		
1614	F	389	19.5		

(1) See Figure 2.11.

Table C-6. (continued) Position sensitivity measurement data for moderated source.

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Detector: Ludium Model 15

time	position (1)	scale setting	1000s of counts per minute	cps	position (1)	average cps
1255	A	10	0.051	8.50	A	9.28
1257	A	10	0.058	9.67	B	9.44
1259	A	10	0.058	9.67	C	8.89
1339	B	10	0.050	8.33	D	8.56
1339	B	10	0.060	10.0	E	8.78
1339	B	10	0.060	10.0	F	9.44
1306	C	10	0.060	10.0	All	9.06
1308	C	10	0.040	6.67		
1310	C	10	0.060	10.0		
1402	D	10	0.050	8.33		
1404	D	10	0.052	8.67		
1406	D	10	0.052	8.67		
1346	E	10	0.054	9.00		
1348	E	10	0.054	9.00		
1350	E	10	0.050	8.33		
1328	F	10	0.050	8.33		
1330	F	10	0.060	10.0		
1332	F	10	0.060	10.0		

Detector: Ludium Model 12-4

time	position (1)	scale setting	mrem per hour	cps (2)	position (1)	average cps
1311	A	1	1.00	11.9	A	13.5
1313	A	1	1.20	14.3	B	15.1
1316	A	1	1.20	14.3	C	16.3
1319	A	1	1.40	16.7	D	13.5
1259	B	1	1.40	16.7	E	15.9
1301	B	1	1.00	11.9	F	14.3
1302	B	1	1.20	14.3	All	14.6
1402	C	1	1.40	16.7		
1404	C	1	1.50	17.9		
1406	C	1	1.20	14.3		
1355	D	1	1.20	14.3		
1358	D	1	1.00	11.9		
1400	D	1	1.40	16.7		
1330	E	1	1.20	14.3		
1333	E	1	1.40	16.7		
1336	E	1	1.20	14.3		
1342	F	1	1.40	16.7		
1344	F	1	1.00	11.9		
1345	F	1	1.00	11.9		

(1) See Figure 2.11.

(2) See Section 2.6.1 for transformation of mrem/hour to cps.

Table C-6. (continued) Position sensitivity measurement data for moderated source.

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Detector: NNV-470As

time	position (1)	counts per 20 seconds	cps	position (1)	average cps
1330	A	380	19.0	A	18.3
1331	A	350	17.5	B	19.2
1334	A	370	18.5	C	20.4
1354	B	387	19.4	D	17.9
1356	B	382	19.1	E	18.7
1359	B	385	19.3	F	18.5
1257	C	391	19.6	All	18.8
1300	C	427	21.4		
1301	C	407	20.4		
1340	D	357	17.9		
1344	D	335	16.8		
1346	D	382	19.1		
1309	E	381	19.1		
1313	E	391	19.6		
1315	E	348	17.4		
1402	F	345	17.3		
1405	F	391	19.6		
1406	F	373	18.7		

Detector: Jomar Model JSP-12

time	position (1)	1000s of counts per 100 seconds	cps	position (1)	average cps
1352	A	29.6	296	A	296
1355	A	29.5	295	B	294
1357	A	29.7	297	C	285
1403	B	29.4	294	D	272
1405	B	29.4	294	E	280
1407	B	29.3	293	F	282
1338	C	28.2	282	All	285
1340	C	28.7	287		
1342	C	28.5	285		
1331	D	27.5	275		
1333	D	27.1	271		
1335	D	27.2	272		
1258	E	28.1	281		
1259	E	27.9	279		
1302	E	28.0	280		
1319	F	28.2	282		
1321	F	28.3	283		
1323	F	28.1	281		

(1) See Figure 2.11.

Table C-6. (continued) Position sensitivity measurement data for moderated source.

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Detector: Ludium 42-9

time	position (1)	counts per 60 seconds	cps	position (1)	average cps
1403	A	185	3.08	A	3.51
1404	A	199	3.32	B	3.43
1405	A	248	4.13	C	3.13
1329	B	187	3.12	D	3.52
1331	B	223	3.72	E	3.09
1334	B	208	3.47	F	3.62
1352	C	211	3.52	All	3.38
1353	C	211	3.52		
1354	C	142	2.37		
1311	D	182	3.03		
1314	D	220	3.67		
1318	D	231	3.85		
1340	E	196	3.27		
1341	E	186	3.10		
1343	E	174	2.90		
1258	F	224	3.73		
1259	F	234	3.90		
1301	F	194	3.23		

Detector: Bubble Dosimeter

time	position (1)	average bubbles per 720 seconds (2)	cps	total counts	position (1)	average cps
1330	A	6.00	0.00833	108	A	0.0150
1330	A	13.3	0.0185		B	0.0204
1330	A	5.30	0.00736		All	0.0177
1330	A	21.0	0.0292			
1330	A	22.7	0.0315			
1330	A	9.30	0.0129			
1330	A	10.3	0.0143			
1330	A	5.70	0.00792			
1330	A	8.00	0.0111			
1330	A	6.70	0.00931			
1310	B	14.7	0.0204	147		
1310	B	18.0	0.0250			
1310	B	9.00	0.0125			
1310	B	9.30	0.0129			
1310	B	24.7	0.0343			
1310	B	11.3	0.0157			
1310	B	11.0	0.0153			
1310	B	22.0	0.0306			
1310	B	13.0	0.0181			
1310	B	14.0	0.0194			

(1) See Figure 2.11.

(2) See introductory text in this Appendix for an explanation of fractions of bubbles in the data tables.

Table C-7. INF measurement data for moderated source.

2/18/93

Detector: INF (No Other Detectors Present)

time	distance (cm)	counts per 100 seconds	cps	r (cm)	average cps
1120	100	1.22E+05	1220	100	1220
1122	100	1.22E+05	1220	200	368
1125	100	1.22E+05	1220		
1134	200	3.72E+04	372		
1136	200	3.61E+04	361		
1137	200	3.72E+04	372		

Detector: INF (Other Detectors Present)

time	distance (cm)	counts per 100 seconds	cps	average cps (1)
1258	100	1.20E+05	1200	1210
1300	100	1.20E+05	1200	
1303	100	1.20E+05	1200	
1310	100	1.21E+05	1210	
1313	100	1.21E+05	1210	
1315	100	1.21E+05	1210	
1330	100	1.21E+05	1210	
1333	100	1.21E+05	1210	
1336	100	1.20E+05	1200	

(1) includes all 100cm measurements.

Appendix D
RDE Data from Tests at the Los Alamos Simulation Facility (LASF)

Appendix D: RDE Data from Tests at LASF

Appendix D contains a listing of data collected during the week of RDE testing at the Los Alamos Simulation Facility (LASF). The data are presented in the following order:

- Background measurement data
- ^{252}Cf measurement data
- Radial measurement data for the INF detector with "nominal" ^{252}Cf source
- Am(Li) measurement data for unshielded sources
- Am(Li) measurement data for shielded sources

Table D-1. Background measurement data.
(page 1 of 4)

Detector: NNV-470As

time	counts/20sec			average counts/20sec	average cps
3/30/93					
0900	1	1	3	2.14	0.107
	1	3	2		
	4	3	1		
	5	2	3		
	6	2	0		
	1	1	2		
	2	1	1		
0915	1	1	1	1.88	0.0938
	1	0	1		
	6	1	2		
	2	1	4		
	1	2	3		
	3				
1550	0	3	2	1.25	0.0625
	0				
3/31/93					
0905	1	2	2	1.90	0.0950
	3	2	3		
	0	4	1		
	1				
1330	5			5.00	0.250
1345	1			1.00	0.050
4/1/93					
0900	3	6	5	3.75	0.19
	4	7	6		
	1	1	1		
	2	3	6		
1315	2			2.00	0.100
1415	3	3	5	3.83	0.19
	3	3	2		
	2	7	4		
	4	5	5		

Table D-1. Background measurement data.
(page 2 of 4)

Detector: INF

time	counts/100sec		average counts/100sec	average cps
3/30/93				
0945	206	225	237	2.37
	246	232		
	271	239		
1315	383	385	384	3.84
1430	330	352	343	3.43
	347			
1515	391	362	377	3.77
1550	362		362	3.62
1720	398	368	383	3.83
3/31/93				
0905	355	370	380	3.80
	416			
1233	220	240	230	2.30
1330	686		686	6.86
4/1/93				
0900	822	885	875	8.75
	873	880		
	917			
1030	374		374	3.74
1315	971	1020	990	9.90
	984	983		
1415	907	902	914	9.14
	933			

Table D-1. Background measurement data.
(page 3 of 4)

Detector: Jomar Model JSP-12			
3/30/93			
time	counts/100sec	average counts/100sec	average cps
0900	42	39.3	0.393
	35		
	41		
0915	35	34.7	0.347
	29		
	40		
1440	36	47.5	0.475
	48		
	57		
	49		
1515	30	29.5	0.295
	29		
1550	33	33.0	0.330
1720	47	46.0	0.460
	45		
3/31/93			
0905	69	49.7	0.497
	40		
	40		
1330	70	70.0	0.700
1345	76	76.0	0.760
4/1/93			
0900	116	103	1.03
	86		
	108		
1315	91	91.0	0.910
1415	80	87.3	0.873
	68		
	114		

Table D-1. Background measurement data.
(page 4 of 4)

Detector: INF

time	counts/100sec		average counts/100sec	average cps
3/30/93				
0945	206	225	237	2.37
	246	232		
	271	239		
1315	383	385	384	3.84
1430	330	352	343	3.43
	347			
1515	391	362	377	3.77
1550	362		362	3.62
1720	398	368	383	3.83
3/31/93				
0905	355	370	380	3.80
	416			
1233	220	240	230	2.30
1330	686		686	6.86
4/1/93				
0900	822	885	875	8.75
	873	880		
	917			
1030	374		374	3.74
1315	971	1020	990	9.90
	984	983		
1415	907	902	914	9.14
	933			

Table D-2. Californium measurement data.

Calibrated Cf Measurements—Detectors 1m from Source

3/31/93

1330

Detector: NNV-470As

counts/20sec	average counts/20sec	average cps
32	31.7	0.317
30		
33		

Detector: Ludlum Model 42-9

counts/120sec	average counts/120sec	average cps
99	92.0	0.920
83		
94		

Detector: Jomar Model JSP-12

counts/100sec	average counts/100sec	average cps
12840	12900	129
12940		

Detector: INF

counts/100sec	average counts/100sec	average cps
27100	27000	270
27000		
26900		

Nominal Cf Radial Measurements

3/30/93

1330

Detector: INF

r (cm)	counts/100s	r (cm)	average cps
50	7450	50	75.5
50	7650	75	40.2
75	3940	100	26.4
75	4100	125	18.4
100	2600	150	14.6
100	2670	200	10.5
125	1820		
125	1860		
150	1400		
150	1520		
200	1070		
200	1020		

Table D-3. Am(Li) measurement data for unshielded source. (page 1 of 2)

Weak Am(Li) Measurements--Detectors 1m from Unshielded Source
3/30/93

Detector: NNV-470As

time	counts/20sec		average counts/20sec	average cps
1100	1	1	1.90	0.0950
	2	0		
	2	2		
	0	2		
	3	1		
	1	2		
	2	2		
	4	0		
	1	5		
	4	3		

Detector: Ludlum Model 42-9

time	counts/120sec		average counts/120sec	average cps
1100	1	3	2.50	0.0208
	2	4		

Detector: Jomar Model JSP-12

time	counts/100sec		average counts/100sec	average cps
1100	77	83	78.0	0.780
	76	76		
1440	87	86	86.5	0.865

Detector: INF

time	counts/100sec		average counts/100sec	average cps
1100	376	380	379	3.79
	380	381		
1400	515		515	5.15

Weak Am(Li) Measurements--Detectors 0.5m from Unshielded Source
3/31/93

Detector: NNV-470As

time	counts/20sec		average counts/20sec	average cps
1315	2	2	3.00	0.150
	4	3		
	4			

Detector: Ludlum Model 42-9

time	counts/120sec	average counts/120sec	average cps
1315	4	4.00	0.0333

Table D-3. Am(Li) measurement data for unshielded source.
(page 2 of 2)

Strong Am(Li) Measurements--Detectors 1m from Unshielded Source
3/30/93

Detector: NNV-470As

time	counts/20sec		average counts/20sec	average cps
1555	71	71	65.2	3.26
	71	48		
	65			

Detector: Ludium Model 42-9

time	counts/120sec		average counts/120sec	average cps
1555	123	135	132	1.10
	139			

Detector: Jomar Model JSP-12

time	counts/100sec		average counts/100sec	average cps
1555	11350	11263	11300	113
	11270			

Detector: INF

time	counts/100sec		average counts/100sec	average cps
1555	41200	41100	41300	413
	41300	41400		

Strong Am(Li) Measurements--Detectors 0.5m from Unshielded Source
3/31/93

Detector: NNV-470As

time	counts/20sec		average counts/20sec	average cps
1015	230	199	218	10.9
	197	244		
	217	208		
	240	217		
	213	214		

Detector: Ludium Model 42-9

time	counts/120sec		average counts/120sec	average cps
1020	426	414	424	3.53
	432			

Table D-4A. Am(Li) measurement data for "weak" shielded source. (page 1 of 2)

Weak Am(Li) Measurements--Detectors 1m from Shielded Source

3/30/93

Detector: NNV-470As

Shielding: 2.54cm Poly

time	counts/20sec			average counts/20sec	average cps
1145	3	1	2	2.33	0.117
	3	4	0		
	2	7	2		
	3	2	2		
	2	2	3		
	2	2	1		
	5	0	1		

Detector: Ludium Model 42-9

Shielding: 2.54cm Poly

time	counts/120sec		average counts/120sec	average cps
1145	3	0	1.00	0.00833
	1	0		

Detector: Jomar Model JSP-12

time	counts/100sec		average counts/100sec	average cps
Shielding: 2.54cm Poly				
1145	57	70	65.5	0.655
	69	66		
Shielding: 5.08cm Poly				
	55	43	50.3	0.503
	48	55		
Shielding: 1.90cm Wood				
	68	79	75.7	0.757
	80			
Shielding: 2.54cm Wood				
	85	71	75.0	0.750
	69			
Shielding: 2.54cm Wood & 2.54cm Poly				
	49	40	48.7	0.487
	57			
Shielding: 2.54cm Wood & 5.08cm Poly				
	55	27	39.3	0.393
	36			

Table D-4A. Am(Li) measurement data for "weak" shielded source.
(page 2 of 2)

Weak Am(Li) Measurements--Detectors 1m from Shielded Source (continued)

3/30/93

Detector: INF

Shielding: 2.54cm Poly

time	counts/100sec		average counts/100sec	average cps
1145	453	414	428	4.28
	425	442		
	404			

Shielding: 5.08cm Poly

	366	403	389	3.89
	402	384		

Shielding: 1.90cm Wood

	534	508	496	4.96
	442	499		

Shielding: 2.54cm Wood

	486	534	507	5.07
	502			

Shielding: 2.54cm Wood & 2.54cm Poly

	412	435	428	4.28
	438			

Shielding: 2.54cm Wood & 5.08cm Poly

	388	387	388	3.88

Weak Am(Li) Measurements--Detectors 0.5m from Shielded Source

3/31/93

Detector: NNV-470As

Shielding: 2.54cm Wood

time	counts/20sec			average counts/20sec	average cps
1315	4	2	3	3.60	0.180
	2	7			

Detector: Ludlum Model 42-9

Shielding: 2.54cm Wood

time	counts/120sec	average counts/120sec	average cps
1315	2	2.00	0.0167

Table D-4B. Am(Li) measurement data for "strong" shielded source.
(page 1 of 7)

Detector: NNV-470As

Strong Am(Li) Measurements--Detector 1m from Shielded Source
4/1/93

Shielding: 5.72cm Poly

time	counts/20sec			average counts/20sec	average cps
1325	102	109	112	110	5.48
	116	114	115		
	116	101	105		
	117	98			

Shielding: 3.50cm Poly

1325	131	151	152	160	7.98
	163	163	156		
	182	158	174		
	165				

Shielding: 8.26cm Poly

1325	73	54	62	54.8	2.74
	67	51	59		
	46	58	57		
	56	47	27		

Shielding: 13.3cm Poly

1325	26	17	15	18.0	0.90
	16	12	12		
	24	21	19		
	12	25	17		

Shielding: 18.4cm Poly

1325	12	10	16	10.2	0.511
	10	12	7		
	10	9	6		

Shielding: 23.5cm Poly

1325	10	6	11	8.92	0.446
	5	9	4		
	6	7	12		
	8	14	16		
	8				

Table D-4B. Am(Li) measurement data for "strong" shielded source.
(page 2 of 7)

Detector: NNV-470As

Strong Am(Li) Measurements--Detector 1m from Shielded Source
4/1/93

Shielding: 5.72cm Poly

time		counts/20sec		average counts/20sec	average cps
1325	102	109	112	110	5.48
	116	114	115		
	116	101	105		
	117	98			

Shielding: 3.50cm Poly

1325	131	151	152	160	7.98
	163	163	156		
	182	158	174		
	165				

Shielding: 8.26cm Poly

1325	73	54	62	54.8	2.74
	67	51	59		
	46	58	57		
	56	47	27		

Shielding: 13.3cm Poly

1325	26	17	15	18.0	0.90
	16	12	12		
	24	21	19		
	12	25	17		

Shielding: 18.4cm Poly

1325	12	10	16	10.2	0.511
	10	12	7		
	10	9	6		

Shielding: 23.5cm Poly

1325	10	6	11	8.92	0.446
	5	9	4		
	6	7	12		
	8	14	15		
	8				

Table D-4B. Am(Li) measurement data for "strong" shielded source.
(page 4 of 7)

Detector: Jomar Model JSP-12

Strong Am(Li) Measurements--Detector 1m from Shielded Source
3/30/93

Shielding	time	counts/100sec	average counts/100sec	average cps
2.54cm Poly	1555	5253	5230	52.3
		5255		
		5179		
5.08cm Poly	1555	2464	2440	24.4
		2446		
		2407		
2.54cm Wood	1555	9529	9460	94.6
		9326		
		9531		
2.54cm Wood & 2.54cm Poly	1555	4008	4070	40.7
		4144		
		4057		
2.54cm Wood & 5.08cm Poly	1555	1902	1930	19.3
		1865		
		2015		
5.08cm Borated Poly	1555	3729	3710	37.1
		3701		
		3703		
10.2cm Borated Poly	1555	1685	1680	16.8
		1677		
		1685		
1.60mm Cd Sheet	1555	11490	11500	115
		11420		
		11700		
1.60mm Cd Sheet & 2.54cm Poly	1555	5586	5550	55.5
		5616		
		5470		
1.60mm Cd Sheet & 5.08cm Poly	1555	2463	2490	24.9
		2567		
		2443		

Table D-4B. Am(Li) measurement data for "strong" shielded source. (page 5 of 7)

Detector: Jomar Model JSP-12

Strong Am(Li) Measurements—Detector 1m from Shielded Source (continued)

3/31/93

Shielding: 7.62cm Poly

time	counts/100sec	average counts/100sec	average cps
0925	1493	1520	15.2
	1517		
	1534		

4/1/93

Shielding: 5.72cm Poly

time	counts/100sec	average counts/100sec	average cps
1315	2704	2750	27.5
	2713		
	2843		

Shielding: 3.50cm Poly

time	counts/100sec	average counts/100sec	average cps
1315	6203	6150	61.5
	6080		
	6160		

Shielding: 8.26cm Poly

time	counts/100sec	average counts/100sec	average cps
1315	1209	1190	11.9
	1151		
	1199		

Shielding: 13.3cm Poly

time	counts/100sec	average counts/100sec	average cps
1315	269	265	2.65
	275		
	252		

Shielding: 18.4cm Poly

time	counts/100sec	average counts/100sec	average cps
1315	179	173	1.73
	163		
	177		

Shielding: 23.5cm Poly

time	counts/100sec	average counts/100sec	average cps
1315	156	169	1.69
	181		
	170		

Table D-4B. Am(Li) measurement data for "strong" shielded source.
(page 6 of 7)

Detector: INF

Strong Am(Li) Measurements--Detector 1m from Shielded Source
3/30/93

Shielding: 2.54cm Poly

time	counts/100sec	average counts/100sec	average cps
1555	26100	26300	263
	26500		
	26400		

Shielding: 5.08cm Poly

time	counts/100sec	average counts/100sec	average cps
1555	16000	16100	161
	16300		
	15900		

Shielding: 7.62cm Poly

time	counts/100sec	average counts/100sec	average cps
1555	9340	8730	87.3
	9310		
	8100		
	8150		

Shielding: 10.2cm Poly

time	counts/100sec	average counts/100sec	average cps
1555	16000	16100	161
	16300		
	15900		

Shielding: 2.54cm Wood

time	counts/100sec	average counts/100sec	average cps
1555	40400	40400	404
	40600		
	40200		

Shielding: 2.54cm Wood & 2.54cm Poly

time	counts/100sec	average counts/100sec	average cps
1555	24000	23500	235
	23700		
	22900		

Shielding: 2.54cm Wood & 5.08cm Poly

time	counts/100sec	average counts/100sec	average cps
1555	12300	12100	121
	12200		
	11900		

Shielding: 5.08cm Borated Poly

time	counts/100sec	average counts/100sec	average cps
1555	14100	14100	141
	14100		
	14100		

Shielding: 10.2cm Borated Poly

time	counts/100sec	average counts/100sec	average cps
1555	7010	7190	71.9
	7260		
	7310		

Shielding: 1.60mm Cd Sheet & 2.54cm Poly

time	counts/100sec	average counts/100sec	average cps
1555	30900	30900	309

Shielding: 1.60mm Cd Sheet

time	counts/100sec	average counts/100sec	average cps
1555	40800	40800	408

Shielding: 1.60mm Cd Sheet & 5.08cm Poly

time	counts/100sec	average counts/100sec	average cps
1555	16100	16100	161

Table D-4B. Am(Li) measurement data for "strong" shielded source.
(page 7 of 7)

Detector: INF

Strong Am(Li) Measurements--Detector 1m from Shielded Source (continued)

3/31/93

time	counts/100sec	average counts/100sec	average cps
Shielding: 2.54cm Poly			
1010	3220	3220	32.2
Shielding: 5.08cm Poly			
1010	1660	1660	16.6
Shielding: 7.62cm Poly			
1010	8560	8560	85.6
Shielding: 10.8cm Poly			
1010	5580	5580	55.8
4/1/93			
Shielding: 5.72cm Poly			
1315	20400	20500	205
	20800		
	20300		
Shielding: 3.50cm Poly			
1315	45900	45800	458
	45800		
	45600		
Shielding: 8.26cm Poly			
1315	8570	8700	87.0
	8810		
	8720		
Shielding: 13.3cm Poly			
1315	2000	2020	20.2
	2020		
	2030		
Shielding: 18.4cm Poly			
1315	1420	1380	13.8
	1310		
	1410		
Shielding: 23.5cm Poly			
1315	1310	1300	13.0
	1310		
	1270		

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